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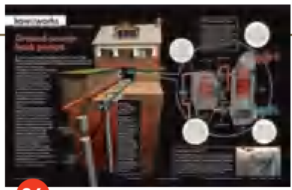

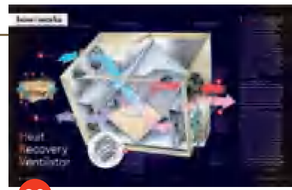

HOW IT WORKS

departments

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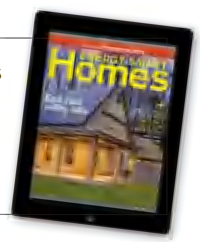

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Fine Homebuilding: (ISSN: 1096-360X) is published bimonthly, with a special 7th issue in the spring and a special 8th issue in the fall, by The Taunton Press, Inc., Newtown, CT 06470-5506. Telephone (203) 426-8171. Periodicals postage paid at Newtown, CT 06470 and at additional mailing offices. GST paid registration #123210981.

Subscription Rates: U.S., $37.95 for one year, $65.95 for two years, $93.95 for three years. Canada, $40.95 for one year, $71.95 for two years, $102.95 for three years (GST included, payable in U.S. funds). Outside the U.S./Canada: $45.95 for one year, $81.95 for two years, $117.95 for three years (payable in U.S. funds). Single copy U.S., $7.99. Single copy Canada, $8.99.

Postmaster: Send address changes to Fine Homebuilding, The Taunton Press, Inc., 63 South Main Street, PO Box 5506, Newtown, CT 06470-5506.

Canada Post: Return undeliverable Canadian addresses to Fine Homebuilding, c/o Worldwide Mailers, Inc., 2835 Kew Drive, Windsor, ON N8T 3B7, or email to mnfa@taunton.com.

Printed in the USA

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contributors

THE VOICES OF EXPERIENCE

STEVE DeMETRICK ("Detailing Walls With Rigid Foam," pp. 104-107) is the owner of DeMetrick Housewrights, a residential building company in Rhode Island that specializes in high-performance building, millwork, and high-end remodeling. A certified Passive House contractor, he just completed the first certified Passive House in Rhode Island. When he's not air-sealing European windows or making custom stair parts, Steve enjoys life with his wife and children.

Architect **STEVE BACZEK** has designed hundreds of houses across a spectrum of energy performance. In addition to his design work, he is the author of over a thousand energy-smart construction details for GreenBuildingAdvisor.com. Steve shares his knowledge of architecture and building science at conferences around the country. This issue includes two of his articles: "All-Around Efficient," pp. 40-45, and "Build a Risk-Free Finished Basement," pp. 114-119.

A former editor at *Fine Homebuilding*, **SEAN GROOM** ("Is Solar the Solution?" pp. 30-35) is now a freelance writer and editor in Simsbury, Conn. He's done stints as a teacher, remodeling contractor, marketing analyst, and full-time athlete. As a writer and editor, he has covered some of the most complex topics in the world of building. He begins most mornings with a bike ride before moving on to writing, remodeling, and coaching soccer.

As a residential designer with a background in carpentry and engineering, **MIKE MAINES** ("Mineral Wool Makes a Comeback," pp. 68-73) pays attention to the practical, hardworking parts of a house. He recently completed Passive House Designer training. For design inspiration, he draws on nature and on traditional, vernacular architecture. When not designing, Mike likes to work in his woodshop or tend to his homestead in rural Maine.

write an article

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editor'snote

THE VIEW FROM MY DESK

Futuristic performance in a familiar form. *This house in Norwich, Vt., is a prime example of how creative energy-saving solutions and modern technology can be integrated with familiar, even downright traditional, forms. (See the finished house on p. 14.)*

We all have a lot to learn

During my 11 years at *Fine Homebuilding,* I've worked on dozens of energy-related feature stories, researched and wrote about progressive building materials, and interviewed people whose building intelligence operated at a far higher level than my own. I've attended building-science seminars that may as well have been in a different language, and I've even spent several months with an architect and team of builders to see what it truly takes to build a certified Passive House. (Check out our video series on this house at FineHomebuilding.com/extras.)

The lesson I've learned over and over again is to distrust anybody who thinks they have "the perfect house" all figured out. Instead, I pay attention to the ones who never stop researching (see "Mineral Wool Makes a Comeback," pp. 68-73) and who never stop holding a lens up to new technologies (see "Is Solar the Solution?" pp. 30-35, and "Installing a Minisplit," pp. 74-78). I'm also drawn to those who have the courage to experiment, not only with new products and techniques but also with how the old ways can be integrated with the new (see "The Evolution of Efficiency: Net Zero as the New Normal," pp. 14-19).

Like it or not, the science of a house is incredibly complicated, and we all have a lot to learn. Just when you're sure that you've got all those air barriers and vapor retarders in the right place, that you've found the perfect insulation, or that you finally understand the subtleties of moisture migration, you're likely to find out that you and everyone you know has been caulking joints incorrectly (see "Caulk This Way," pp. 84-89). How's that for humbling?

That's why we at *Fine Homebuilding* love to prepare special issues like this one. If we can learn from those who are the best at what they do, we all will build better homes.

—JUSTIN FINK, editor, *Energy-Smart Homes*

Photo: courtesy of Prudent Living

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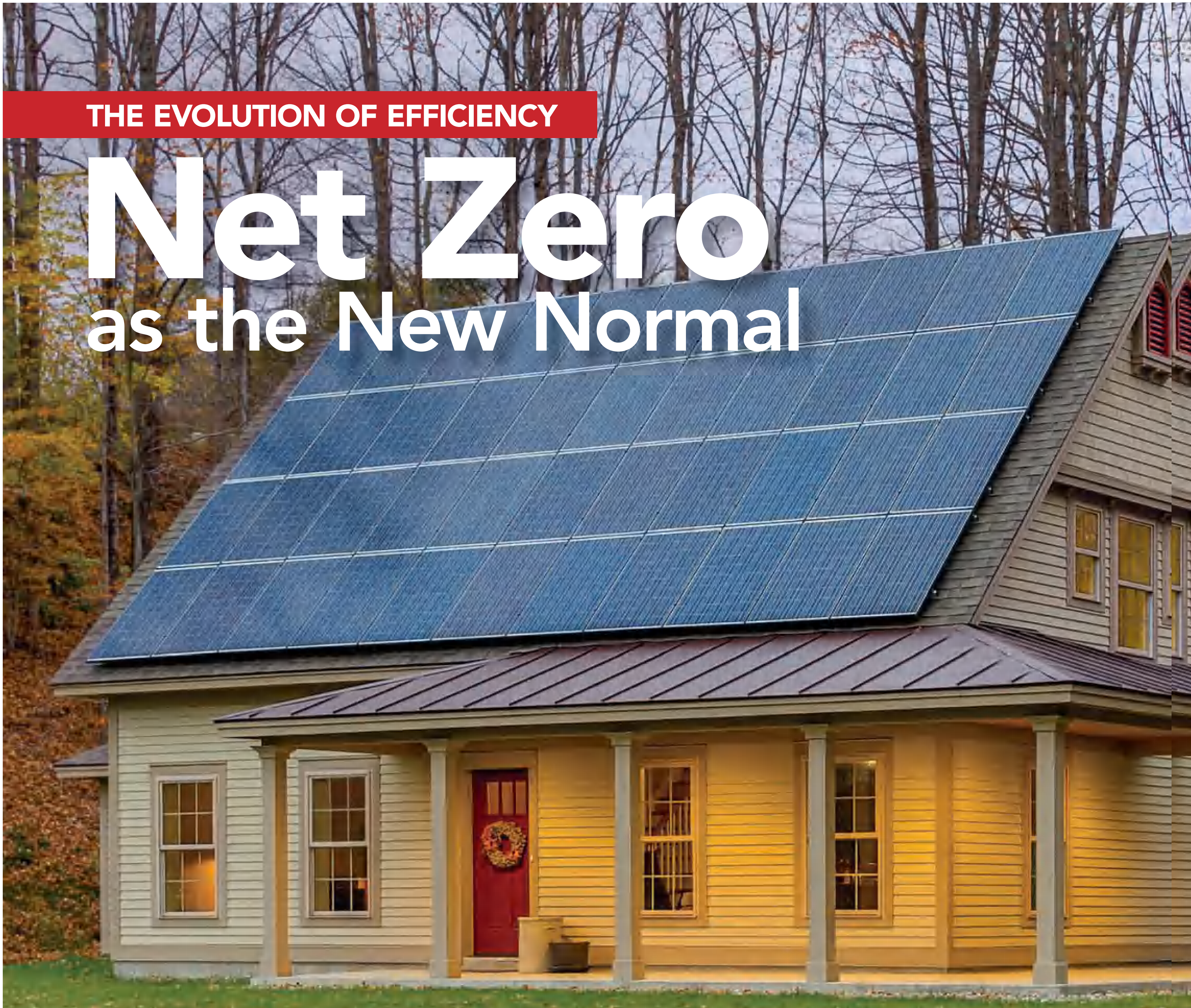
ENERGY-SMART Homes

Theories put into practice



THE EVOLUTION OF EFFICIENCY

Net Zero as the New Normal

Experimentation and learning have led one builder to integrate energy-smart techniques into everyday construction

BY MARTIN HOLLADAY

Biologists note that when unrelated species occupy the same environment, evolutionary changes sometimes alter those species in similar ways. After millions of years, a swimming bird like a penguin, a swimming mammal like a dolphin, and a swimming fish like a shark tend to resemble each other: They all have sleek, smooth bodies and propel themselves with similar motions. This is an example of convergent evolution.

A parallel example is becoming evident in the world of residential construction. In New England, builders who have been paying attention to energy issues for the last 20 years and a subset of builders who attend conferences and constantly push their techniques to the next level are beginning to exhibit signs of convergent evolution. As these forward-thinking builders learn new concepts, experiment with their implementation, and share their successes and failures with fellow builders, homes they build are beginning to resemble each other. These net-zero-energy homes are often compact two-story designs with the long axis oriented in an east-west direction, and most have triple-glazed windows and walls with high R-values. Increasingly,

Photo this page: Gary Hall. Drawing facing page: John Hartman.

these homes are equipped with roof-mounted photovoltaic (PV) arrays and are heated and cooled by ductless minisplits. Custom builder Paul Biebel, president of Prudent Living Homes in Vermont, is a prime example of this ongoing evolution.

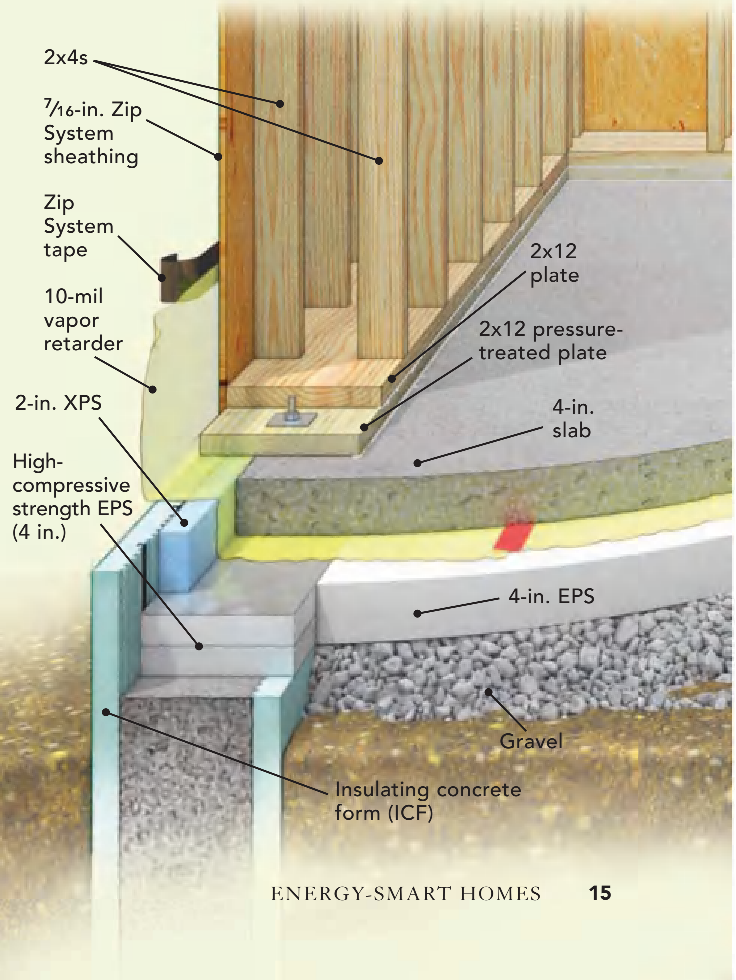
Four decades on the learning curve

The 2500-sq.-ft. house in Norwich, Vt., shown here was completed in 2015, Biebel's 39th year of building houses. "We build five or six custom houses per year, and it's probably been six or seven years since

A SMART SLAB ASSEMBLY

More than a structural base for the house, the stemwalls and slab separate the conditioned living space from the cold earth. Here, the insulation, air-sealing, and moisture-control details all must work together.

ICFs as slab-edge insulation. *By stopping the concrete pour for the stemwalls about 8 in. shy of the ICFs' top edge, the inner flange of the forms can be cut off to make room for a double layer of 2-in.-thick high-compressive-strength EPS foam atop the stemwalls, with 4-in.-thick foam added in the rest of the field. The remaining outer edge of the ICFs provides insulation for the slab edge.*



THICK, TALL WALLS

Arguably one of the simplest and most cost-effective ways to achieve a superinsulated wall, double-stud framing provides an excellent thermal break, especially when combined with the selective use of spray foam. To allow the cavity insulation to run uninterrupted from bottom plate to roof rafters, the framers built balloon-framed walls, then hung the floor system from a ledger.

One on top of the other. *After the interior section of the double-stud wall is assembled, the outer section is framed atop it, with plywood flanges separating the two sections. The entire assembly is sheathed and tipped into place in one piece.*

we've built one just to code minimum," Biebel says. "Nobody likes to be a guinea pig, but we have incorporated new approaches and technology slowly over the years, little by little."

Homeowners who invest in these features from the start, including the incremental costs in a 30-year mortgage, end up with very low energy bills. In fact, these features are often cash-flow positive from day 1. Regarding the cost required to hit this mark, Biebel says, "If you add $30,000 up front to make the upgrades, you will have made that money back in six to eight years, all while having no utility bills." But it's more than avoiding utility bills; according to Biebel, it's about making a smart investment. "To me, this is about preparing for the future," he says. "What is your house going to be worth 10 years from now if it doesn't perform at that level? I see investing in this technology as protecting your investment."

It begins with the shell

Although Biebel's houses are custom, they follow a high-performance baseline. The foundation consists of perimeter stemwalls—insulated concrete forms (ICFs) from Nudura—with an additional layer of rigid foam installed along the outside edge of the slab. A 4-in. layer of foam under the slab is rated at R-20.

Biebel builds two kinds of walls: double-stud walls filled with cellulose (R-45) and 2x6 cellulose-filled walls with rigid foam on the outside (R-40) for clients concerned about interior square footage. At the base of the walls in this house, the sheathing is taped to the 10-mil Stego Wrap vapor barrier that was installed directly under the concrete-slab foundation to create a continuous air barrier up the wall and eventually across the top plate and up the inside face of the roof rafters.

The roof on a Biebel house is at least R-60, even if there's a cathedral ceiling instead of a traditional attic. This high level of insulation is achieved with 20-in.-deep trusses, which allow enough room for 2-in.-deep site-built ventilation channels and 18 in. of dense-pack cellulose. If a more conventional attic is built, Biebel ramps the R-60 minimum to a more robust R-90, simply because the incremental cost is easy to justify when blowing loose-fill cellulose on an attic floor.

Directly above the ceiling drywall on the second floor, a layer of taped Zip System sheathing creates a durable air barrier. This sheathing layer is tied into a layer of self-adhered flashing that crosses over the top plates of the exterior walls and is sealed to the sheathing on the outside face. The insulation follows the roof slope rather than the kneewall, and the drywall air barrier is hung before any kneewalls are framed.

In some places, such as on the breezeway between the house and the insulated garage, spray foam was used to insulate the roof in order to achieve a high R-value in a relatively compact space. In cases like this, Biebel applies a 1-in. layer of rigid foam to the top of the rafters or trusses to create a thermal break. Strapping and plywood are then added over the foam, forming a free-flowing ventilation channel under the roofing. "Although this isn't required with closed-cell foam," Biebel says, "we were informed by our suppliers that the shingle companies do not give a full warranty on any roof that is foamed tight to the underside."

Biebel's blower-door test results (1 ACH50) justify the air-sealing efforts. The crew tests houses after the air-sealing and insulation are complete, and then again when the house is finished. "Our numbers would probably be lower if we could install casement windows," Biebel says. "But all our customers want double-hungs."

Cellulose belt, spray-foam suspenders. *Although primarily insulated with dense-pack cellulose, all penetrations are coated first with spray polyurethane foam, and all seams in wall plates are sealed with a bead of caulk.*

In all of his builds, Biebel uses triple-glazed windows that have a whole-window U-factor of 0.19 and a solar heat-gain coefficient of 0.25. The vinyl windows shown here are Harvey Building Products' Tribute units.

"Harvey only charges $50 per window to upgrade from double to triple glazing; some manufacturers charge an additional $200 per window," Biebel says. "The window package for this house cost less than $10,000, which is half the price of the same package from some other manufacturers."

Inside the tight and well-insulated shell, the focus moves to a successful integration of mechanicals.

Learning to get the most from minisplits

Biebel has been heating and cooling his homes with Mitsubishi ductless minisplits for several years. (For more on minisplits, see "Installing a Minisplit," pp. 74-78.) This house has two outdoor units: one for the ductless units and one for the ducted system. Biebel's cost to install a ductless minisplit in a house with multiple indoor heads is usually between $3000 and $4000 per head. "A ducted system can cost twice as much as a ductless system," he says, "but we do offer it as an option for those clients who don't want to see the minisplit head mounted on the wall."

There is a learning curve to locating minisplits. "You have to think about special conditions," Biebel explains. "A house we built in New Hampshire was located at the end of a long, narrow pond, and the pond created a wind-tunnel effect. We put the outdoor unit under the deck, thinking that it was protected. But the fan and coils got packed with snow. The solution in that case was to move the outdoor unit to the street side of the house."

Noise is also an issue. "There is always some vibration from the outdoor units, so it's important to choose the location carefully," Biebel says. "When things are quiet, you can hear a vibration or hum."

Inside the house, the routes for the refrigerant and condensate lines need to be planned carefully. "In some cases, you may need custom framing to accommodate them," Biebel says. "You need to miss any important timbers or beams. Some homes require 50 ft. or more of

DEEP-TRUSS ROOF

Combining the proven benefits of traditional attic ventilation with superinsulation strategies, these deep trusses yield an R-60 roof and cathedral ceiling by way of some clever site-built details.

Superinsulated, vented cathedral. *The 20-in.-deep trusses provide space for site-built ventilation baffles that are made from ripped 2x stock and ½-in. OSB and are sealed at all joints with canned foam. The remaining 18 in. of space is then dense-packed with cellulose to provide an R-60 lid.*

Air-seal before adding kneewalls. *To provide a reliable air barrier at the ceiling plane, the underside of the roof trusses is covered with Zip System sheathing and seam tape, then covered with drywall before the kneewalls are framed.*

refrigerant line." Condensate lines either can be directed to a leaching system under the slab, or they can go right to the radon pipes, but depending on a trap connected to the DWV system is risky. "When the traps dry out," says Biebel, "you get odors."

The air handler for this house's ducted minisplit is located in a conditioned attic. Although the space is cramped, the HVAC contractor managed to squeeze in the ducted minisplit unit and the Renewaire energy-recovery ventilator (ERV) under the rafters, keeping them inside the insulated envelope to minimize thermal losses.

Mechanical beauty is in the eye of the beholder

As a designer, Biebel prides himself on his attention to integrating ductless-minisplit heads into the interior design of his houses. (The Mitsubishi head in this kitchen is centered over a base cabinet.) "To make a heat-pump head look natural takes a lot of planning," Biebel says. "One thing I've learned is that ugly is in the eye of the beholder. Some people like the minisplit heads, while other people call them ugly. Some people even think solar panels are ugly. Once we were building a house with a solar array, and neighbors stopped by to complain about the solar panels. I replied, 'What if I complained because I thought that your junky vehicles looked ugly?' They got the point and laughed."

The roof-mounted 13kw PV array on this house should produce more electricity on an annual basis than the homeowners need for lights, appliances, plug loads, domestic hot water, space heating, and cooling. "The owners didn't really need 13kw," Biebel confesses, "but

MECHANICALS MAKE IT PAY

When the air-sealing and insulating are done well, the burden on a home's mechanical systems is greatly reduced. Small heating and cooling units are able to condition the home to a comfortable level, and they can be powered by the sun's energy.

Beauty is in the eye of the PV-holder. *Some consider solar panels ugly, but these homeowners increased the size of the PV array beyond their energy requirements for aesthetic reasons, believing the house would look better if the entire roof were covered.*

More than a random placement. *Rough-ins for the minisplit's outdoor units are considered carefully, not only for aesthetic reasons but because they create noise from their vibration.*

they said that the roof would look better if we just went ahead and covered the entire south-facing slope with PV."

Biebel isn't force-feeding solar to his clients, though. "If homeowners aren't interested in going off the grid, or even in adding solar panels, that's OK," he says, "but we plan for that anyway by deciding where the solar inverters would be placed, and we provide conduits from the attic to the basement so that the necessary electrical can be installed without opening walls."

Energy will trump square footage and location

Biebel predicts that the time is coming when energy consumption will be a bigger part of the conversation about house design than location or square footage. "Right now, banks and appraisers only look at square footage and at the value of the house next door," he says. "They'll need to catch up." Biebel has chosen the route of building high-performance homes even though it has meant turning down clients who are interested only in getting the lowest cost per square foot. His reasoning includes equal parts altruism and genuine belief in offering his clients something with lasting value. "I want to put green back in the Crayola box where it belongs," he says. "The only way I see that happening is to make it a normal part of the conversation, not an upgrade." □

Martin Holladay is a senior editor at GreenBuildingAdvisor.com and at *Fine Homebuilding*. Justin Fink also contributed to this article. Photos courtesy of Prudent Living, except where noted.

Designing for

An updated HUD guide demonstrates that a durable house is also a dry house

BY JAY CRANDELL AND JAMIE LYONS

Have you Googled "housing durability" lately? Probably not. But you might be surprised that one of the most popular downloads on the U.S. Department of Housing and Urban Development's (HUD) website is a guide we were commissioned to write called *Durability by Design*. It's a collection of best design practices for housing durability from the ridge vent to the footings, and it covers moisture, UV radiation, corrosion, mechanicals, insects, and other topics. According to Dana Bres of HUD, who was instrumental in creating both the original guide and its recent update, one reason it's been so popular is that "the practices which make for good durability are often the same ones that make houses more sustainable and efficient. In searching for those details, builders and designers find us."

It struck us that the original 2002 publication is kind of like a time capsule that shows the building methods and materials commonly used in that era. "Era" makes it sound long ago, but homes really do work a lot differently today than they did a decade ago, and this affects durability. We've seen these changes along the way through our work in building consulting, training, research, inspections, and forensics, but updating this 12-year-old durability guide really put the changes into focus for us.

Here we highlight some of the most important topics in the new version of the guide. We hope you'll give the new guide a read and find it as interesting as we did in producing it.

Jay Crandell, P.E., and Jamie Lyons, P.E., are engineers specializing in residential durability and energy. They are the co-authors of HUD's *Durability by Design*.

ONLINE EXTRA To download a PDF of the new *Durability by Design* guide, visit newportpartnersllc.com.

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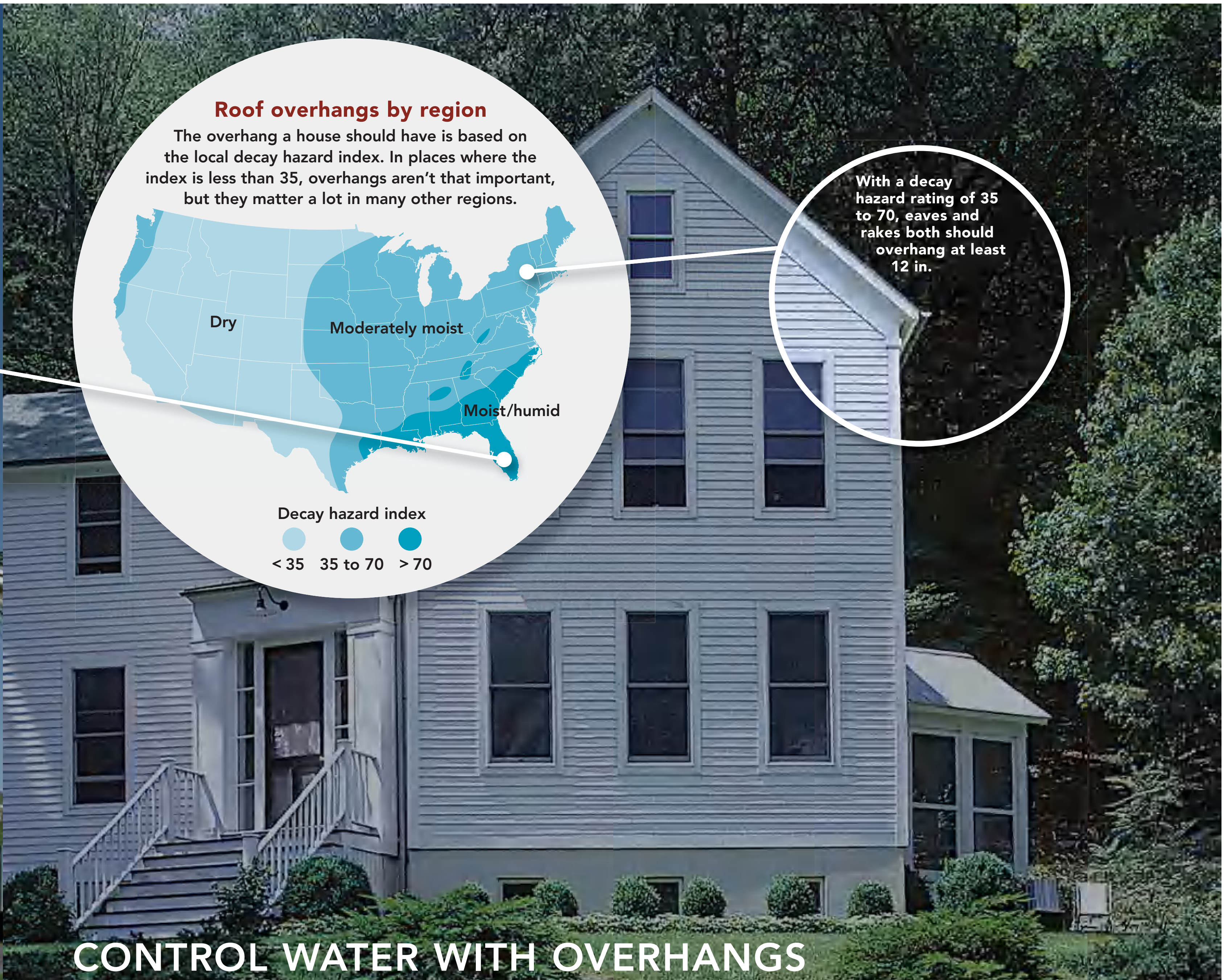
Durability



CONTROL WATER WITH OVERHANGS

Rainwater control has always topped the list of durability-fostering details. The improved insulation and air-sealing of today's exterior walls means that they have a greater sensitivity to moisture. Keeping rain from hitting walls, which is the job of roof overhangs, is more important than ever. In the revised guide, we place the important factors for rainwater management into a clear decision-making framework that includes recommendations for roof-overhang width based on risk of decay—which differs by region—as a way to reduce the risk of water intrusion in walls.

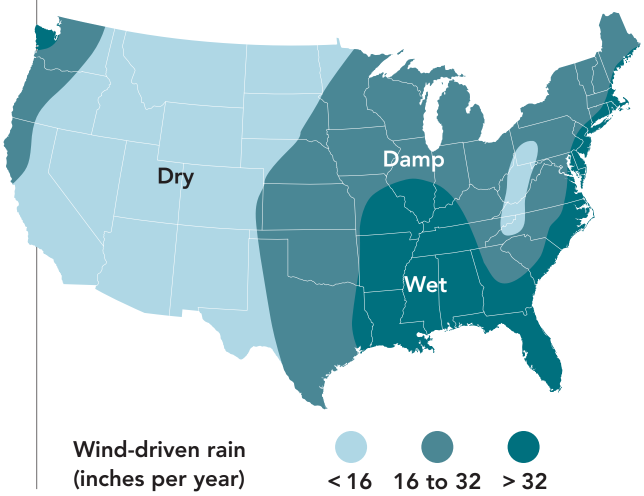
DESIGN WALLS BASED ON LOCAL RAINFALL

Although a wall's durability and performance depend on far more than its exterior cladding, the design and installation of that cladding and its underlayment are critical factors in protecting a building from rainwater and moisture accumulation. The revised guide lays out a three-step procedure for selecting a durable and climate-appropriate method of constructing exterior walls to ensure performance in specific climates.

STEP 1

ASSESS THE SITE'S CLIMATE

Begin by categorizing the climate based on the potential for wetting of walls, especially wetting from wind-driven rain. These classifications are a bit subjective, as there aren't clearly defined criteria in the United States for assessing the effects of wind-driven rain. As a proxy, we use a wind-driven-rain map in the revised guide to help classify the severity of the climate.



STEP 2

ASSESS BUILDING EXPOSURE

The terrain surrounding a building affects its exposure to wind-driven rain, as does the ratio of roof overhang to the height of the wall below. Increased shielding of the site against wind tends to reduce the effects of rain. Similarly, wide roof overhangs relative to wall height effectively reduce the exposure.

Reference the table at right to determine a building's exposure level based on the climate, the roof-overhang ratio, and the wind. The exposure level provides a basis for selecting an appropriate exterior-wall assembly. We can drill down further by applying the exposure levels in the table to specific walls of a house or even elements such as glazing. By understanding the exposure at this simplified level, a builder or designer can make decisions about flashing details or consider the benefits of using wider overhangs.

BUILDING EXPOSURE LEVELS

Wind exposure	Overhang ratio*	Site climate		
		Wet	Damp	Dry
Little or no wind protection from surrounding buildings and/ or natural obstructions	0	High	High	Moderate
	0.1	High	Moderate	Low
	0.2	Moderate	Low	Low
	0.3	Moderate	Low	Negligible
	0.4	Low	Low	Negligible
	≥ 0.5	Low	Negligible	Negligible
Wind protection from surrounding buildings and/ or natural obstructions	0	High	High	Moderate
	0.1	High	Moderate	Low
	0.2	Moderate	Low	Negligible
	0.3	Low	Negligible	Negligible
	0.4	Low	Negligible	Negligible
	≥ 0.5	Negligible	Negligible	Negligible

*Find the overhang ratio by dividing the roof overhang by the wall height.

Photo: Charles Bickford. Drawings facing page: Christopher Mills.

STEP 3

SELECT A WALL ASSEMBLY

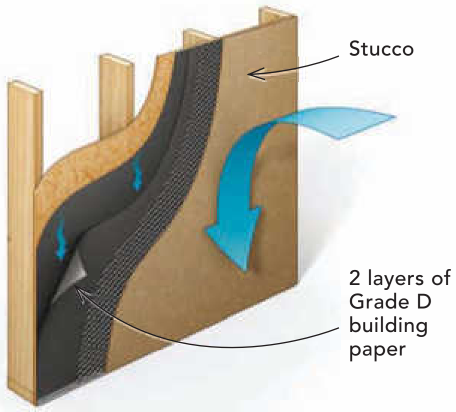
Based on the building exposure level determined in step 2, use the table at right to select an appropriate exterior-wall assembly. With a reasonable level of installation quality and maintenance, a wall rated "good" has a low risk of failure during its likely service life. A "fair" wall may require more careful attention to detailing, installation quality, and maintenance, and it has a tolerable risk of failure during the likely service life. "Not recommended" means that the wall shouldn't be used on a wood-framed house in that climate.

RELATIVE PERFORMANCE OF EXTERIOR-WALL ASSEMBLIES

Exposure level	Concealed barrier	Drained cavity	Basic rain screen
High	Not recommended	Fair	Good
Moderate	Fair	Good	Good
Low	Good	Good	Good
Negligible	Good	Good	Good

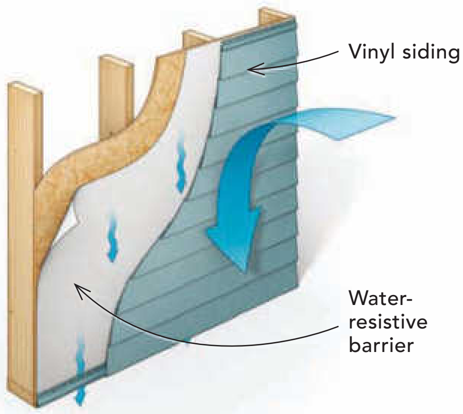
Concealed barrier

The concealed-barrier method relies on porous cladding material adhered to or placed directly on an internal water barrier or drainage plane. A common example is conventional stucco applied over two layers of Grade D building paper. This method relies primarily on deflection of rainwater, but it also has some ability to absorb and retain moisture, which can dry out later. These walls allow water to seep out through weeps at the bottom, but there is no open pathway to allow water to drain freely. Also, moisture stored in the cladding from a recent rain can be driven into the wall by the sun as vapor, especially when the wall uses a vapor-permeable water-resistive barrier (WRB) material such as building paper and many housewraps. Synthetic stone is another example of a concealed-barrier cladding.



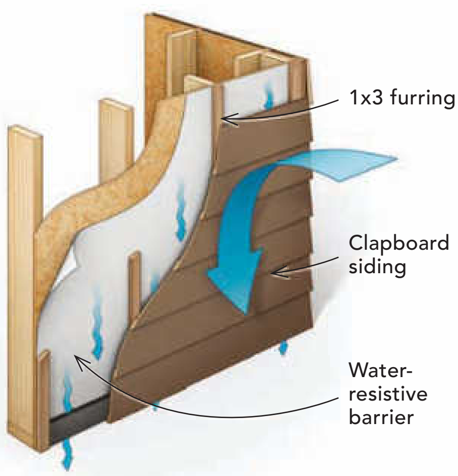
Drained cavity

Drained cavities increase the life of exterior finishes on wood surfaces by promoting drying. The method relies on deflection, drainage, and drying to protect the wall from moisture damage. In general, a cavity separates the cladding from the surface of the underlying WRB. A minimum cavity depth of 3/8 in. is often recommended, but this may vary. While wood siding might be nailed over spacers to create such cavities, vinyl siding placed directly on the WRB creates a cavity whose continuity is broken at points of contact, and masonry veneer is laid with a minimum 1-in. cavity depth to allow space for drainage as well as placement and mortar excesses. The drained-cavity approach also can be applied to portland-cement stucco with use of a drainage mat or metal lath placed over spacers to create the cavity.



Basic rain screen

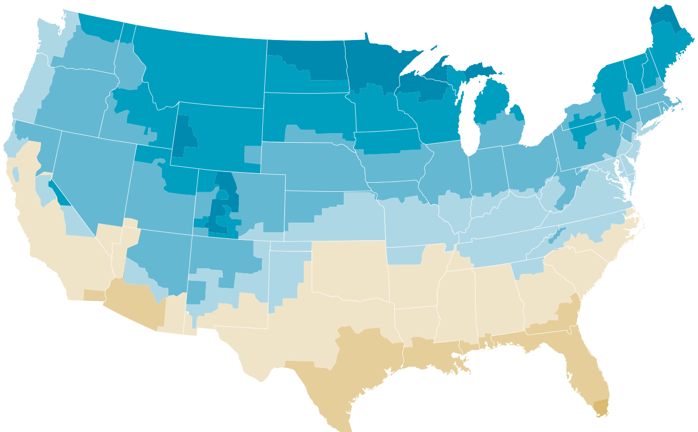
A rain screen is similar to the drained-cavity method, but it has added features to reduce air-pressure differentials across the cladding system that can occur during wind-driven rain. Pressure differentials can draw water into the drainage cavity. At a minimum, this approach uses a rigid air barrier such as sheathing behind the cladding that is able to resist wind pressures. This reduces wind pressure across the cladding (which is not airtight) and is less likely to result in water being sucked behind the cladding. Also, the cavity between the cladding and the water/air barrier must be compartmentalized by use of airtight blocking or furring at corners of the building. This feature prevents water from being sucked into the cavity due to a pressure difference on an adjacent wall. Although the rain-screen method offers improved performance, the simpler drained-cavity method is usually considered a more practical alternative for typical home-building applications.



INSULATE WALLS TO AVOID CONDENSATION

Preventing water vapor from condensing into liquid in walls is incredibly important for durability. Recently added to the International Energy Conservation Code (IECC), continuous rigid exterior insulation combined with traditional batt or blown cavity insulation is detailed as an option for many climate zones. This change can affect how moisture in walls behaves in ways that the code did not seem to anticipate.

We can prevent condensation in walls by keeping the interior of their sheathing from falling below the dew-point temperature. In the prescriptive wall assemblies, the continuous exterior insulation must hold enough heat in, or the cavity insulation must let enough heat through, to keep the sheathing interiors warmer than the dew point. Durability requires a climate-specific look at the ratio between the R-values of the exterior insulation and the cavity insulation, as well as the permeance of the vapor retarder.



Minimum insulation ratios for U.S. climate zones

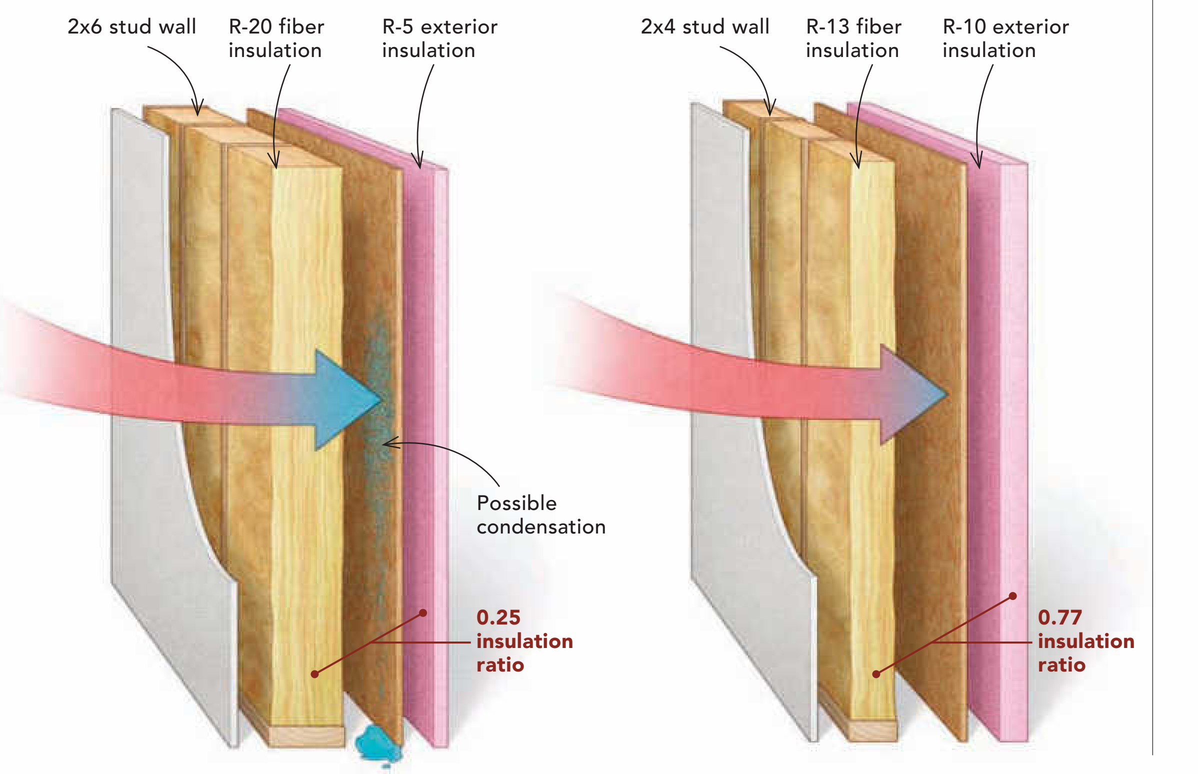
Climate zone	Class II interior vapor retarder	Class III interior vapor retarder
1 to 3	No limit	
4	0.2	
5	0.2	0.35
6	0.25	0.5
7	0.35	0.7

MATCH THE INSULATION TO THE VAPOR RETARDER

The insulation ratio is the R-value of the exterior insulation divided by that of the cavity insulation. For example, R-5 (1 in. rigid foam) ÷ R-20 (6 in. fiber insulation) = 0.25. Used with low-perm exterior foam insulation, Class I vapor retarders such as plastic can trap moisture. Class II (kraft-paper-faced batts) or Class III vapor retarders (many paints) allow drying to the inside. Using the map and the chart above, match the type of vapor retarder to the insulation ratio and the climate zone to avoid condensation.

THINK BEYOND THE BUILDING CODE

Both the walls below meet code, but one might have condensation in a cold climate. Although the 2012 IECC approves the use of an R-20+5 wall in all climates, that wall's insulation ratio of 0.25 can cause condensation in zones 5 and up if used with a Class III vapor retarder. The IECC considers an R-13+10 2x4 wall to be thermally equivalent to an R-20+5 wall. With an insulation ratio of 0.77, this wall should perform well up to zone 7 with a Class II or Class III vapor retarder.



Bottom drawings: Christopher Mills

BY JOHN STRAUBE

Stopping air is the second-most-important job of a building enclosure. Next to rain, air leaks through walls, roofs, and floors can have the most damaging effect on the durability of a house. Uncontrolled airflow through the shell not only carries moisture into framing cavities, causing mold and rot, but it also can account for a huge portion of a home's energy use and can cause indoor-air-quality problems.

A tight house is better than a leaky house, with a caveat: A tight house without a ventilation system is just as bad as a leaky house with no ventilation system—maybe worse. Energy efficiency requires a tight shell; good indoor-air quality requires fresh outdoor air. Ideally, the fresh air should come not from random accidental leaks of unknown size and quantity, but from a known source at a known rate. For this to happen, the house needs an adequate air barrier and a controlled ventilation path.

In a leaky house, large volumes of air—driven by exhaust fans, the stack effect, and wind—can blow through the floor, walls, and ceiling. Because air usually contains water vapor, these uncontrolled air leaks can cause condensation, mold, and rot (photo below). The

Leaky rim joists matter. *Floor and wall connections offer many air-leakage opportunities. The wall sheathing on this house in Minnesota experienced serious rot because ductwork in the floor framing pulled moist air through poorly sealed rim joists.*

AIR LEAKS

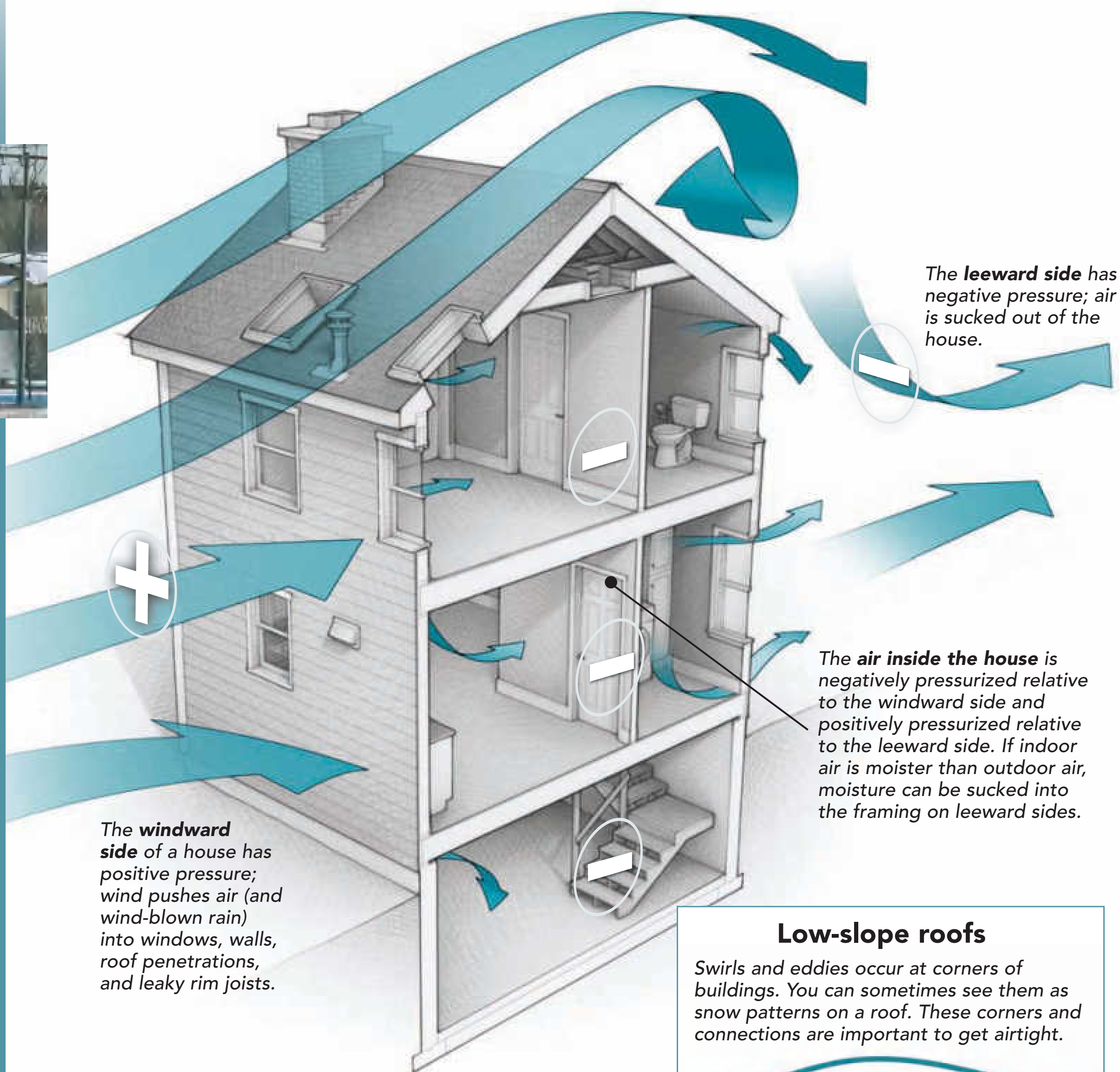
How They Waste Energy and Rot Houses

One-third of the energy you buy probably leaks through holes in your house

Photo: courtesy of the Builders Association of Minnesota

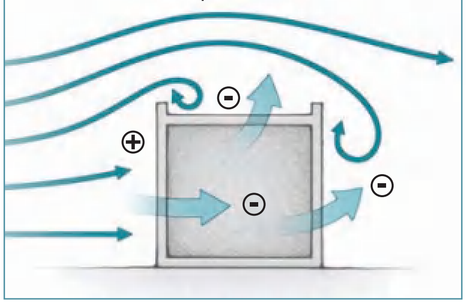
Wind

The wind that pushes air into one side of a house also sucks it out the other side. If the outdoor air is moister than the indoor air, water can be driven into framing on windward sides. On a gusty winter day, the pattern of wind pressure can be seen as swirls around corners and edges that sweep snow from specific areas. It is important to have good air-barrier details where roofs, walls, floors, and foundations meet.



Low-slope roofs

Swirls and eddies occur at corners of buildings. You can sometimes see them as snow patterns on a roof. These corners and connections are important to get airtight.



only way you can know for sure that the air coming into a house is clean is to know where it's coming from. People who say, "I want my house to breathe," are really saying, "I want to rely on the mistakes that were made by the plumber and the electrician to provide me with fresh air." That's exceptionally dangerous. Any air that enters a house through leaks in the building envelope may be loaded with pollutants. The dead squirrel in your attic and the SUV idling in your attached garage are not going to provide you and your family with fresh indoor air.

Many indoor-air-quality problems are related to poor control of the air flowing through an enclosure that has been damaged by exposure to moisture, heat, or UV rays. Good indoor-air quality comes from having a good air barrier. Only with a good air barrier can we know where the air is coming from and have a chance to control that air quality (and quantity).

The importance of an air barrier has long been recognized in Canada, where the national building code has required one for 25 years. In the United States, it's absent from state energy codes and wasn't added to ASHRAE's Energy Efficiency Standard (ASHRAE 90.1) until 2009. In 2006, the International Residential Code introduced language requiring walls to be sealed, and it added a requirement for airtightness testing in 2012. The IECC has required airtightness testing since 2009.

Wind can push and pull air through a leaky house

Many houses built to code are leaky. Air leaks can be responsible for a third or more of the energy loss in a typical house. But what pushes and pulls air through a house? There are three things: wind, fans, and the stack effect. Wind is somewhat predictable, or at least its average speed and direction are. Fans include kitchen and bath exhaust fans, HVAC equipment fans, and clothes dryers. The stack effect generates pressure because warm air rises, pushing up and out on the ceiling in cold weather (see "Stack effect," facing page).

Peak wind loads that are listed in the model building codes are fairly high—usually more than 20 lb. per sq. ft. or 1000 pascals (Pa). On average, however, local wind pressure is quite a bit lower. For a house, 5 Pa is likely, and in a high-rise building, maybe

Photo this page: Daniel Morrison. Photo facing page: courtesy of David Keefe. Drawings: Christopher Mills.

40 Pa, 50 Pa, or 60 Pa. The pressure exerted by a blower door—50 Pa—is roughly equal to the pressure of a 16-mph wind or around 1 lb. per sq. ft.

A low-slope roof (less than 3-in-12 pitch) is usually under negative pressure when the wind blows over it. Air is sucked up through the roof because the aerodynamics of the wind passing over the roof's leading edge cause negative pressure. On a house with a steep roof (more than 3-in-12), the pressure is positive on the windward side and negative on the leeward side.

Wind is highly complicated, however. When wind tries to flow around buildings, the highest pressure is on the "sweet spot" in the middle. As the wind goes around corners, it creates large swirls and negative pressures (visible on snowy roofs after a high wind). Wind-related structural damage often occurs at these high-pressure spots or at areas of low-pressure swirling.

Wind exerts positive pressure on the windward walls of a building, causing air leaks on the side of the building facing the wind. On the leeward side, negative pressure sucks indoor air through walls and windows.

The stack effect: When buildings act like chimneys

Like wind, the stack effect can push large volumes of air through a building envelope. In winter, warm air in a heated building is lighter (less dense) than cold air outside; that warm bubble of air wants to rise up and out. The flow of air leaving the top of the building draws cold air in through cracks at the bottom.

The reverse happens in summer, when hot air outside an air-conditioned house can push cooler indoor air down from the ceiling and out cracks in the basement. This can cause moisture problems on the top floor as humid exterior air is drawn through leaks in the upper floor's walls—especially for houses with leaky rim joists.

The differences in temperature and pressure are less during the summer than during the winter. When it's cold outside, the pressure created by the stack effect is 4 Pa per story; when it's hot, the pressure is about 1.5 Pa per story. However, unlike most other pressures, the stack effect acts every hour of every cold day, so the flows generated by the stack effect are significant.

HVAC equipment can overpower wind and the stack effect

Air pressure created by fans—particularly range hoods, dryer exhausts, and large vent fans—can overwhelm both wind and the stack effect.

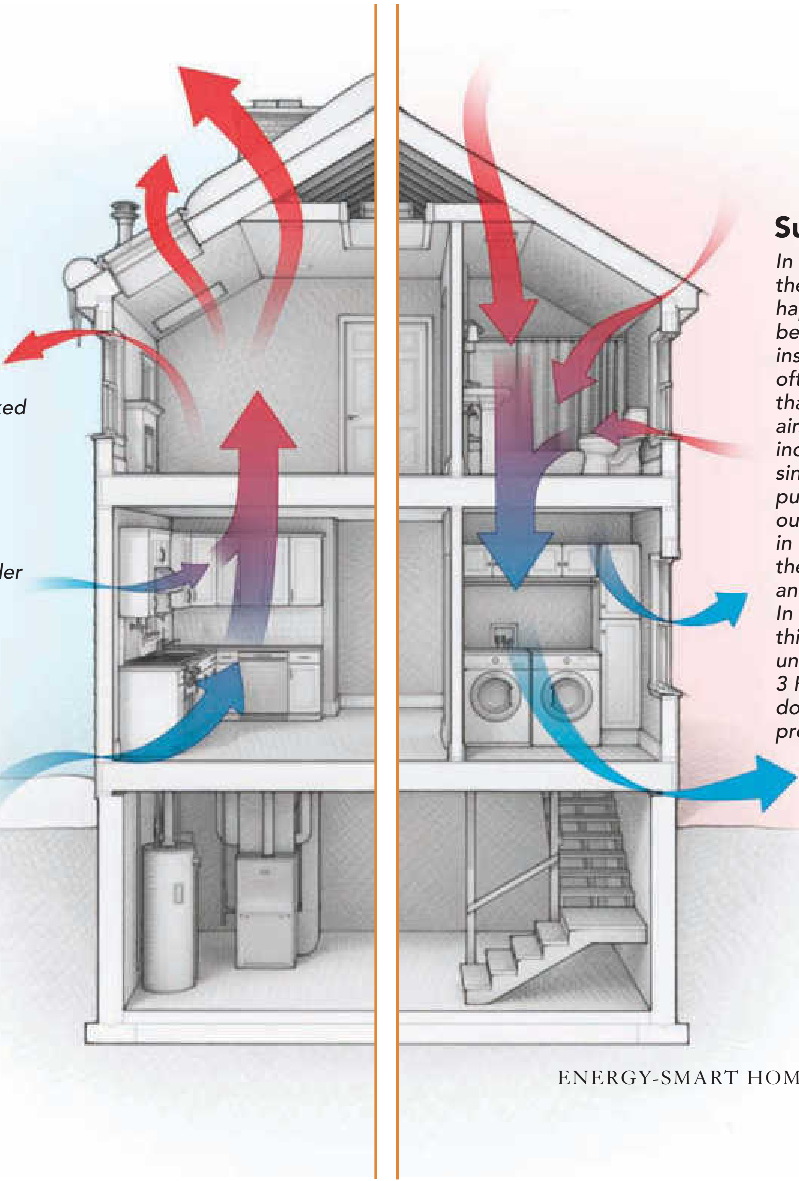
High-end houses often have large, powerful downdraft range hoods with exhaust fans that are rated at 1000 cfm or more. If you don't provide makeup air for such a large volume of exhaust, the whole house will become strongly negatively pressurized. You'll start sucking on the garage, and you'll breathe air sucked backward through your water-heater vent. You'll harvest radon from the soil around the house and suck air

Stack effect

Warm air is more buoyant than cold air. Different air temperatures within a house naturally stratify. As cold air sinks, it pushes up lighter warm air. The stack effect gets more powerful as buildings grow taller. (Note the billowing at the top of the tarp in the photo.) In fact, after skyscrapers were first developed, revolving doors had to be invented because cold air rushed in with so much pressure that it was difficult to pull the doors open from the outside or push them open from the inside.

Winter

In winter, rising warm air escapes through the roof and is replaced by cold air sucked in through the floor. The effect is strongest in winter. This two-story house is under about 8 Pa of constant upward pressure.

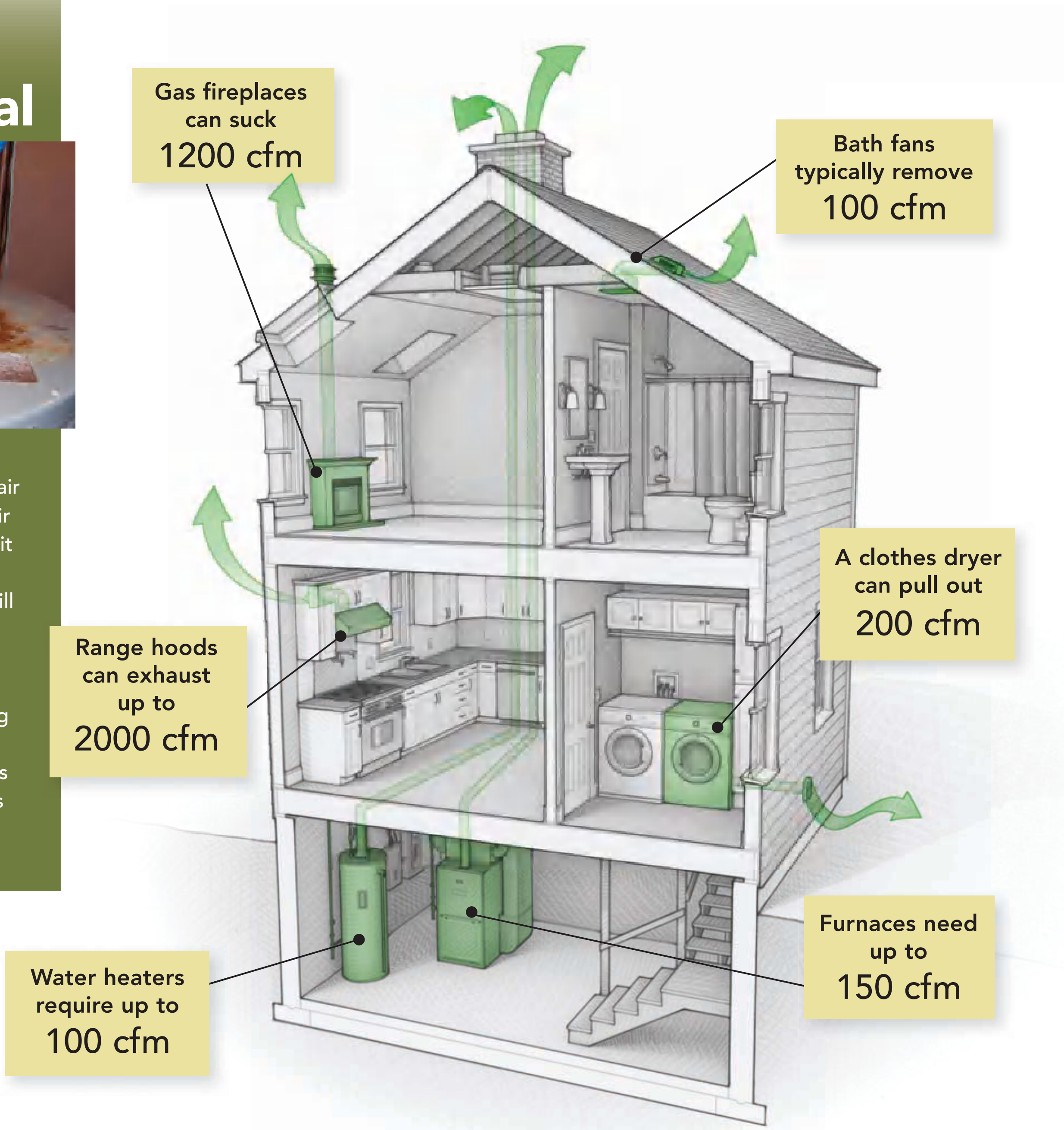


Summer

In summer, the opposite happens because inside air is often cooler than outside air. As dense indoor air sinks, it pulls hot outside air in through the ceiling and roof. In summer, this house is under about 3 Pa of downward pressure.

Mechanical

Clothes dryers, bath fans, and range hoods exhaust air from a house. If makeup air isn't supplied with a duct, it will leak in through cracks. Even worse, makeup air will be backdrafted through combustion appliances, which can cause carbon-monoxide poisoning. Using sealed-combustion appliances and makeup-air units for large range hoods gets around this problem.



backward down your fireplace, bringing deadly carbon monoxide with it. People die every year because of backdrafting created by exhaust appliances.

If you want to avoid sucking air backward through the combustion appliances and cracks in your home, provide makeup air for your range hood, dryer, and other exhaust appliances. The 2009 IRC (M1503.4) requires a separate mechanical makeup-air unit for range hoods of more than 400-cfm capacity.

Moisture rides on air currents

By controlling airflow, you also control the moisture that moves with air. If moist indoor air hits a cold surface, condensation can result. An air barrier prevents cold surfaces from contacting humid indoor air. Air has a maximum storage capacity for water vapor that depends on temperature. Warm air can store lots of moisture, while cold air can store very little. As the temperature falls from 80°F down to 20°F, the amount of moisture that can be stored in the air changes by a factor of 10. This is like a gas tank that shrinks as the temperature gets colder. When it's hot, you can store a lot in this tank; when it's cold, however, you can't store much at all. If you had a large tank filled with gas and you shrunk it, eventually the gas would spill over. That's condensation.

Old leaky homes didn't have condensation problems

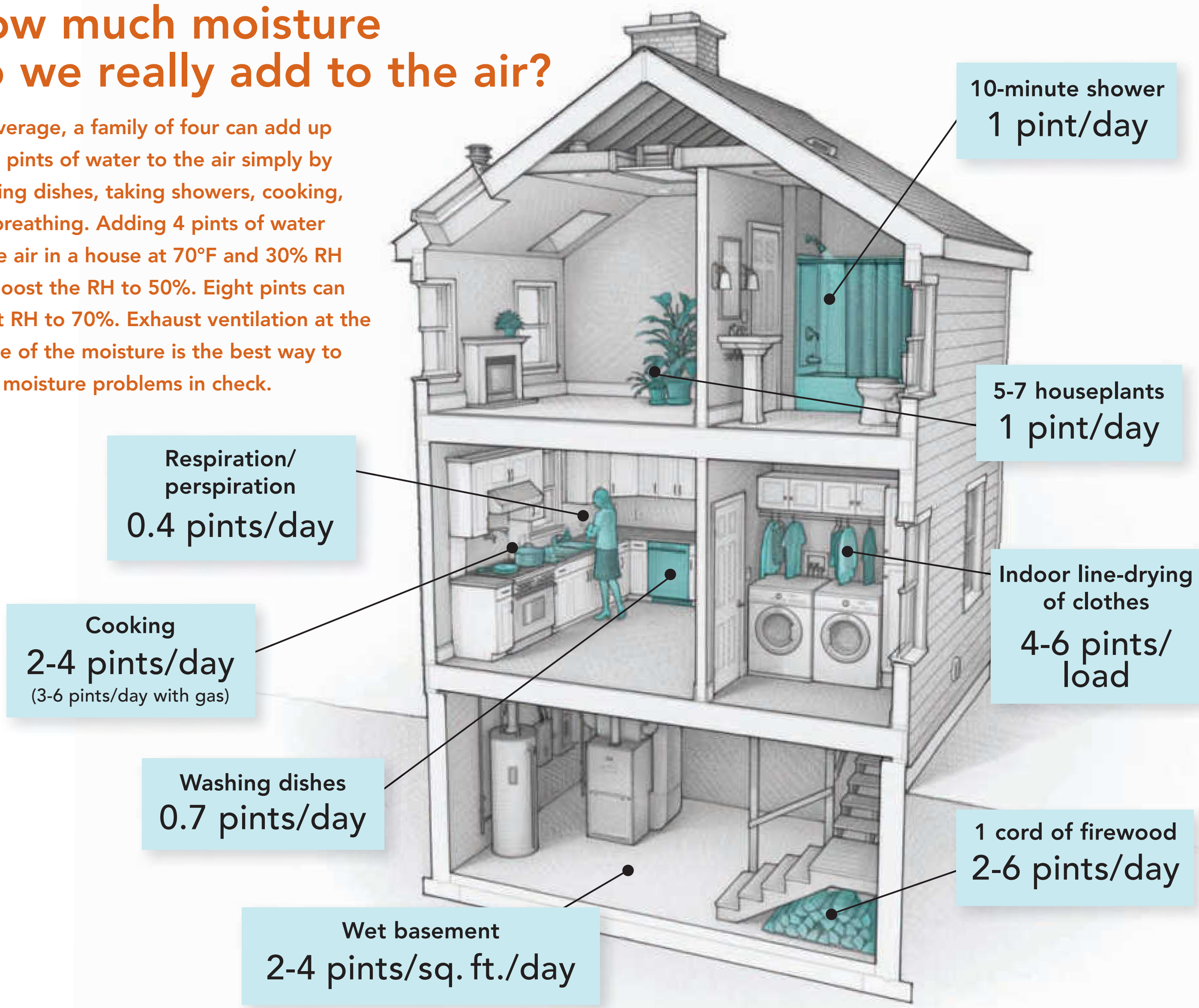
Older buildings rarely had condensation problems in cold weather because they were so leaky. The relative humidity in old houses rarely rose above 25% during the winter. As building codes have progressed, and we have built tighter houses with inadequate or nonexistent mechanical ventilation, the indoor relative humidity (RH) has gone up. In a tight, unventilated house, the amount of moisture in the air is dramatically different from that in an old leaky house. Condensation occurs wherever water vapor can find a cold spot: on the roof or wall sheathing, on the inside faces of the windows, and inside the walls.

Let's say that it's 30°F outside and the outdoor relative humidity is 50%. If that outdoor air enters a 70°F house, the amount of moisture that's in the air stays the same, but the "tank" gets bigger because the storage capacity of the air increases with the temperature. As a result, the relative humidity initially drops. No condensation can occur if the

Photo this page: courtesy of International Association of Certified Home Inspectors

How much moisture do we really add to the air?

On average, a family of four can add up to 25 pints of water to the air simply by washing dishes, taking showers, cooking, and breathing. Adding 4 pints of water to the air in a house at 70°F and 30% RH can boost the RH to 50%. Eight pints can boost RH to 70%. Exhaust ventilation at the source of the moisture is the best way to keep moisture problems in check.



air is heated up. However, once the outdoor air is in the house, moisture is added to the indoor air but the temperature of the house stays the same. Hence, the relative humidity and the absolute moisture content rise. How do you add moisture to the air? You breathe, sweat, boil water, take hot showers, and grow houseplants.

Let's say now that the indoor air leaks out of the house through holes in the enclosure. If the temperature of the outdoor air is around 30°F, the indoor air will drop all of the moisture that it gained while inside on the way out, dumping it on the cold sheathing surface in the form of condensation. Because any condensation that forms in walls can cause puddles—and in extreme cases, can rot the house's framing—condensation is something you want to avoid. Installing an air barrier is one good way to help prevent condensation.

Air-conditioning also can create condensing surfaces

In summer, the same phenomenon can happen in reverse. When hot, humid outdoor air (85°F, 75% RH) leaks inside, the moisture in the air condenses when it hits a surface below about 76°F—for example, on plastic vapor barriers cooled by air-conditioning.

In a tight house with a good air barrier and a supply-only ventilation system, however, most of the air that's drawn inside comes through the air conditioner, so the first cold surfaces it sees are the cooling coils.

If you have air leaks in the envelope, you usually can't see the condensation—unless you're a forensic engineer who goes around cutting holes in walls. However, condensation is sometimes easily visible in the attic. During the winter, all you have to do is look for frost or dampness forming on the underside of the OSB or plywood roof sheathing. It doesn't take much of a hole in the ceiling of a humid house for condensation to accumulate as frost. Then when the sun warms up the black shingle roof, the frost melts, the water falls, and you assume that you have a roof leak. In short, air that leaks through your walls, windows, roof, or basement can result in nothing but trouble. Building tight and ventilating right remain the best advice. □

John Straube, Ph.D., P.Eng., is a professor of building science at the University of Waterloo in Ontario.

Is Solar

Photo: Topher Donahue/Aurora Photos/Corbis

the Solution?

Solar panels might be a wise investment in light of a generous federal tax credit set to expire by 2017

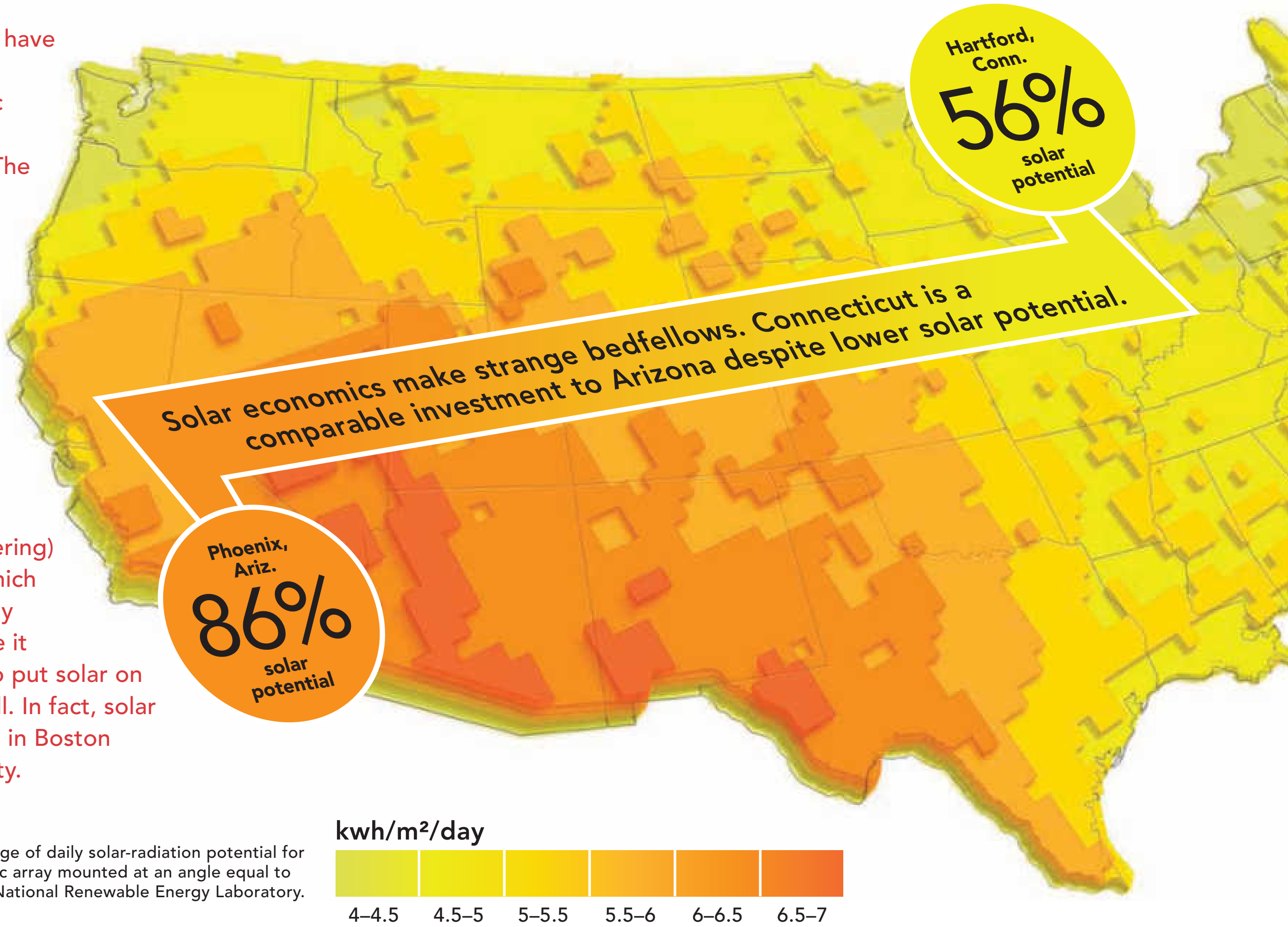
BY SEAN GROOM

Tracking the prices of energy and gasoline is a staple of news reports, but those same reports largely have ignored the steep decline in the cost of photovoltaic (PV) systems—from over $10 per watt in 2000 to around $3.48 per watt in the first quarter of 2015. At this price, solar installers say that there's never been a better time to go solar, and steadily rising electric rates suggest they're right—in principle. However, most Americans are daunted by the perceived substantial cost of a PV system—*perceived* because the average homeowner finds the incentive-riddled pricing structure of PV systems to be murky, is unaware that prices have fallen dramatically, and is often not sure if electric rates are high enough to offset an investment in solar.

Many homeowners still believe that solar is for the wealthy. SolarCity CEO Lyndon Rive has acknowledged in interviews that his company wants to remove the stigma of high costs from solar power. For those who can't afford

PV PARITY

In theory, solar arrays have the biggest payoff in regions where electric rates are high and sunshine is plentiful. The map shows the solar potential of different areas of the country. Phoenix clearly has much more solar potential (86%) because of the amount of sunlight it receives, yet the high utility costs and favorable policies (rebates and net metering) in Hartford, Conn., which has cloud-free sun only 56% of the year, make it economically viable to put solar on your roof there as well. In fact, solar is a better investment in Boston than in any Arizona city.



Map indicates an annual average of daily solar-radiation potential for a south-facing flat photovoltaic array mounted at an angle equal to its latitude. Data courtesy of National Renewable Energy Laboratory.

the up-front cost of purchasing a PV system—and at $13,000 for an average 5kw array after incentives (give or take a few grand), that's a lot of people—solar companies offer financing and leasing plans to replicate the traditional monthly electric payment. They have made going solar more attractive by reducing homeowners' monthly payments and offering price stability over 20 to 30 years.

Solar panels reduce the amount of grid-supplied electricity you must purchase and can be considered an energy-conservation strategy. Unlike with weatherization improvements or switching heating fuels, both the cost of the work and the amount of financial savings with solar are calculated accurately beforehand. If you're looking to save money, it's a straight-off-your-bill deduction independent of other efficiency improvements. To figure out the payoff of adding solar to your rooftop, you need to weigh your electrical usage against the solar potential of your property and compare your utility rate to the installed cost of a solar array.

Supply and demand in an economy of one

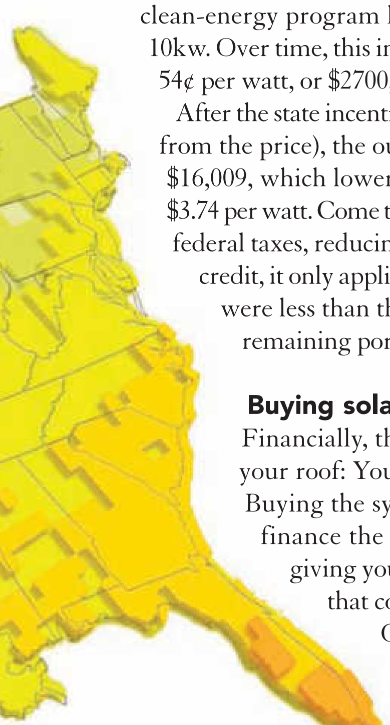
To get a grasp on your personal solar economics, you first need to calculate your demand. Gather the last year (two years if you can) of electrical bills, and tally your monthly usage to arrive at your annual consumption. This is your demand expressed in kilowatt hours (kwh). Last year, for example, my family used 5700kwh. We live in Connecticut and have fairly high utility rates: Our generation charges are 20¢ per kwh, and with transmission and distribution charges, we paid $1200 to power our house for the year.

Supply is the amount of electricity you can produce, in most cases from a rooftop system but alternatively from a ground-mounted array. You can estimate this using the National Renewable Energy Laboratory's PVWatts calculator (pvwatts.nrel.gov). Using satellite-mapping photos, the calculator allows you to mark the area of your roof available for panels and to adjust default variables such as roof slope. The calculator combines this information with geographic, climate, and economic data, and then it spits back the size of the system that will fit on the roof and the amount of energy it will generate during the year. For my roof, it was a 5kw system that would generate 6176kwh per year of electricity—more than enough to offset my annual usage of 5700kwh. Solar companies also perform this calculation, but with an on-site visit to account for shading.

Now that you know demand and supply, the price of the solar array will determine whether it makes sense to purchase one. In July 2015, Sungevity quoted a price of $18,709 for a 5kw system in Connecticut. However, the quoted cost is not the full story. Although state and local incentives generally are winding down, there are still plenty of rebates in force. (You can find state, municipal, and utility incentive programs in the dsireusa.org database. Solar companies in your area

also know the current incentives.) Here in Connecticut, the state's clean-energy program has an incentive for rooftop systems up to 10kw. Over time, this incentive has been reduced, but in July it was 54¢ per watt, or $2700, for a 5kw array.

After the state incentive (paid to the solar company and deducted from the price), the out-of-pocket cost in my example would be $16,009, which lowers the installed cost to $3.20 per watt from $3.74 per watt. Come tax time, I'd be eligible for a 30% credit on my federal taxes, reducing the final cost to $11,206. Because it's a tax credit, it only applies to my tax liability for the year. If my taxes were less than the credit—in this case, $4800 in 2015—the remaining portion of the credit would roll over to 2016.



Buying solar panels is an investment

Financially, there are three ways to get a PV system on your roof: You can buy it outright, finance it, or lease it. Buying the system—whether you pay cash up front or finance the purchase—has the distinct advantage of giving you ownership of the array and the incentives that come with ownership.

Often potential solar customers look at simple payback. Divide the cost of the PV system by the average monthly electric-bill savings, and you've got the number of months until the savings have paid for the system. In my case, this would be during the ninth year, which would make the next 15-plus years of electricity free. An alternative is to divide the total cost of the system—$11,206 in my case, plus $3000 to replace the inverter at some future time—by the total anticipated electrical output over an estimated 25-year life span of the array: 154,400kwh. That works out to roughly 9¢ per kwh (which may be slightly higher depending on how much the panels degrade over time). This simple cost calculation is significantly less than my utility rate, which will increase regularly. Paying for a PV system up front will put a dent in your savings, but it will improve your monthly cash flow—noticeably if you have high electric bills. But financing a PV system may be a better option if you look at going solar as an investment.

The success of many large, national solar companies allows them to offer low-interest, long-term financing for solar arrays. For instance, a $16,000 loan at SolarCity's July 2015 terms (4.5% for 30 years) means that the monthly cost of a fully financed 5kw system is about $81 (plus you get to take the federal tax credit). If your electric rates are high enough to generate significant savings with PV and incentives remain, fully financing an array can gain you a better return even if you have the cash to buy it outright.

Going Solar in America, a recent report by the N.C. Clean Energy Technology Center, compares the net present value (NPV) of purchasing an array to the NPV of financing an array. NPV shows the future (25 years) value of the solar array in present-day dollars. Among the data *Going Solar in America* reports is that the NPV of a 5kw array purchased with cash is $6275 in Boston and $14,987 in San Francisco. Fully financing the same array changes the NPV to $11,830 in Boston and $21,859 in San Francisco. Overall, the report finds that the up-front purchase of a 5kw solar array in 20 of the 50 largest cities in the United States is a better investment than the Standard & Poor's 500 stock index (assuming a 6.61% annual return). But fully financing the array makes it a better investment in 42 of those cities. In regions with low electric rates and/or solar-unfriendly regulatory policies, it's tough to make a return at all on the investment. In Jacksonville, Fla., for example, the NPV of a fully financed array is $2104, but if it's paid for up front, the NPV is –$3871.

As with any investment, it's important to know how liquid it is. If you decide to move, will your home's sale price reflect a premium for the solar array? The Lawrence Berkeley National Laboratory recently compared the sales of almost 4000 homes with solar panels between 2002 and 2013 to a pool of nearly 19,000 non-PV homes picked to match the features of the PV homes (house size, lot size, number of bedrooms, etc.). It found that a solar array adds an average of about $4 per watt to the sale price of a house and that the PV premium over time tended to decline, accounting for falling equipment prices and rebates. (One caveat: The sample for the study didn't allow researchers to look at resale pricing on PV systems more than 10 years old, but it appears that homebuyers depreciate the value of panels quickly.)

Lease plans have broadened the market

Solar companies have used lease and power-purchase agreements (PPA) to broaden their market appeal. Households are used to paying a monthly utility bill; if a solar company can take a cut of that monthly payment and lower the monthly bill for the homeowner, they both win. With a lease, the homeowner pays rent on the equipment and gets the solar production as part of the bargain. The monthly payments are defined for the life of the lease. With a PPA, the equipment is installed free of charge, and the homeowner pays for all the electricity the array produces. The monthly payments are per kwh of

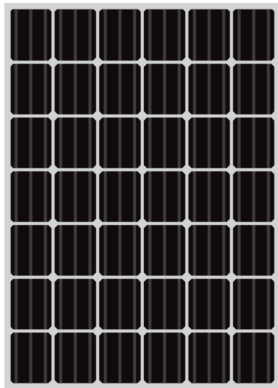
PV PAYMENTS: BUY vs. FINANCE vs. LEASE

The cost of a solar array varies around the country and is affected by hardware costs, demand, and the cost of grid electricity. In many markets, competition is intense, so it's worth getting several estimates to find the best price. The chart shows the average cost of a 5kw array in three states according to SEIA and GMT Research's *Solar Market Insight* report for the second quarter of 2015.

LOCATION OF 5kw ARRAY	BUY Before incentives	FINANCE 0% down, 4.5% APR for 30 years	30-YR. LEASE First year (3% annual increase)
California	$21,550	$109 per mo.	$168 per mo.
Texas	$17,900	$91 per mo.	$115 per mo.
Massachusetts	$24,700	$125 per mo.	$130 per mo.

electricity, typically at or slightly below the retail cost of grid electricity. For both leases and PPAs, there typically is an escalation clause of between 2% and 3% annually. (Nationally, the average utility-rate increase since 2002 is about 4% a year.)

There are some conventions of the leasing and PPA process to know about before meeting with a solar company's representative. If you choose a lease or a PPA, the company installing the panels owns them and cashes in the credits and/or rebates. Another critical thing to know is that leases and PPAs are 20-year contracts. That means if you decide to sell your house, you may be limiting the pool of potential buyers. If the buyer doesn't want to (or isn't approved to) assume the lease, you are responsible for paying the remaining amount due.



Turning the grid into a storage device

Most homes with solar panels are not defecting from the grid. When the PV system produces more electricity than the house is using, the surplus is diverted to the local grid and is consumed by neighbors. When PV production is less than the household's demand, it draws electricity from the grid. The meter keeps track of inflows and outflows, "netting" the monthly usage.

Net metering is an accounting method that lets homeowners effectively time-shift their production and consumption of energy, a critical feature in the economics of residential solar power. The amount of solar energy generated throughout a day varies with the sun's path. Production also varies with the season, diminishing during the winter from shorter, cloudier days and a lower sun path. With consumption waxing and waning throughout the day and the year, peak-use times don't necessarily match up to peak-generation times. Net metering can be understood as a way to turn the grid into a giant storage device that allows homeowners with PV systems to bank excess electricity from high-production periods and then consume it when their demand exceeds their panels' production.

Net metering is required by law in 43 states and the District of Columbia, but the conditions vary. The most advantageous net-metering rules allow homeowners to carry over surpluses from month to month. In these situations, if the array produces more electricity than the home consumes during a month, the utility company issues a credit for the excess production that is rolled over to count against consumption in the upcoming months. In most cases, the homeowner must use up this credit during the solar year, which often runs from July 1 to June 30. If there's a surplus at the end of the year, the credit may expire or the utility may cash out the excess production at a specified tariff. Valuing that excess production has become a matter of dispute.

In most locations, the price a utility assigns to solar electricity is very low because the utility pays the wholesale rate for electricity, also known as the avoided cost, rather than the retail rate that homeowners think of as the price of power. Because reimbursement is so low, it doesn't make sense to invest in an oversize system that will generate a surplus of electricity over the year. That's one reason why checking your historical use when you size the system is important. Another reason is that local incentives may be based on historical usage. Even if that's the case, it's worth considering any future changes to your electricity consumption before sizing the array. If you plan on building an addition, installing a pool, adding central air-conditioning, switching from natural gas or oil to electric, or purchasing a plug-in vehicle, be sure to account for that. Conversely, energy-efficiency improvements can decrease the size of a planned array—although not necessarily at a cost-effective price. It's worth noting that you can't reduce your bill to zero; utilities charge connection/transmission/distribution fees regardless of electrical usage. My utility, for example, charges $19 per month ($228 per year).

Households are used to paying a monthly utility bill; if a solar company can take a cut of that monthly payment and lower the monthly bill for the homeowner, they both win.

Can solar survive without incentives?

The federal 30% tax credit for solar installations is due to expire at the end of 2016. Even if Congress doesn't agree on extending the tax credit (a strong possibility in the current political climate), states' policies could drive down the costs related to permits and inspections from multiple government departments and the utility company. According to a Department of Energy report, these "soft costs" add up to $2500 to the cost of a 5kw system. Removing this red tape—as Vermont has done with a one-page online application for all permits, will help drive down the cost of PV. (See how your state's connection policies rate at freethegrid.com.)

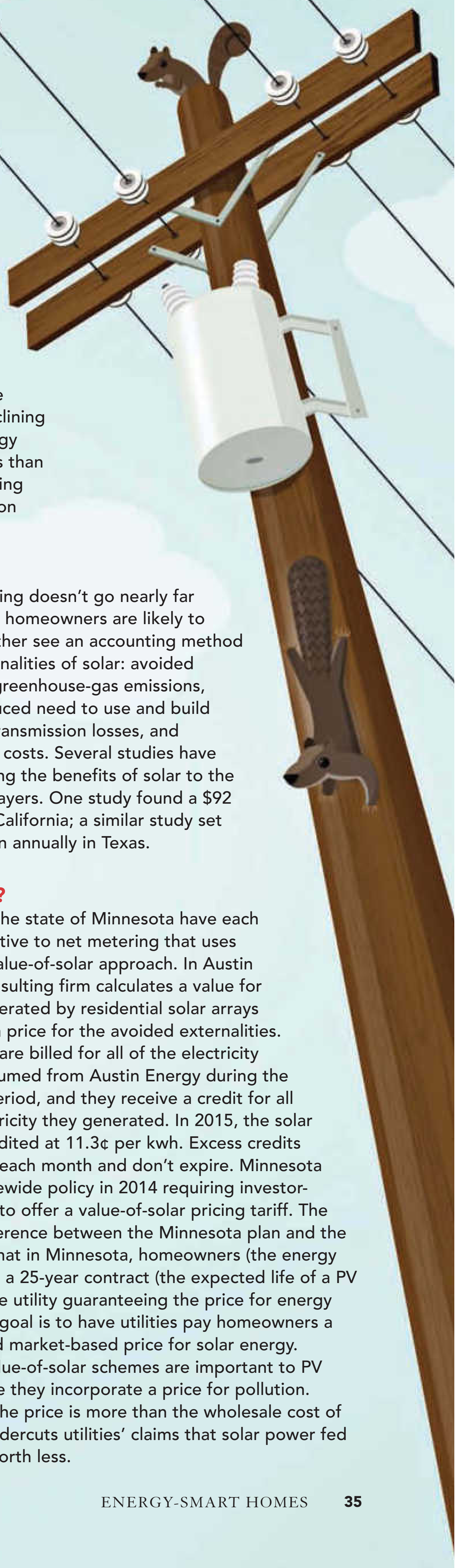
Will solar adoption continue to grow if Congress doesn't renew the credit? Yes, but smaller solar companies may be driven out of business. Solar incentives were introduced to help launch a fledgling industry; as the price of solar hardware has fallen, local incentives have been reduced. Whether in place or expired, these incentives have been remarkably successful. In California and Arizona, state and utility incentives have dried up, yet the rate of solar adoption has accelerated. A recent study by Greentech Media and the Solar Energy Industries Association (SEIA) found that in the first quarter of 2015, nearly 25% of all residential solar installations came online without any state-level or utility-level incentive, up from 2% in 2012. If you're planning on taking advantage of the 30% federal tax credit, keep in mind that the system must be installed before December 31, 2016, and that, depending on the market, it can take from several weeks to several months from when the contract is signed until the system is energized. An unused solar credit cannot be carried over to 2017 if Congress doesn't renew the credit. □

Sean Groom is a contributing editor.

Drawing facing page: John Ueland

PV POWER TO THE PEOPLE

How much does a kilowatt hour of electricity cost? It depends on whom you ask. The fee that utilities pay to suppliers is one amount. Tack on transmission, connection, and distribution charges, and you've got the price consumers pay. What price do you assign to solar energy that homeowners put back onto the grid?

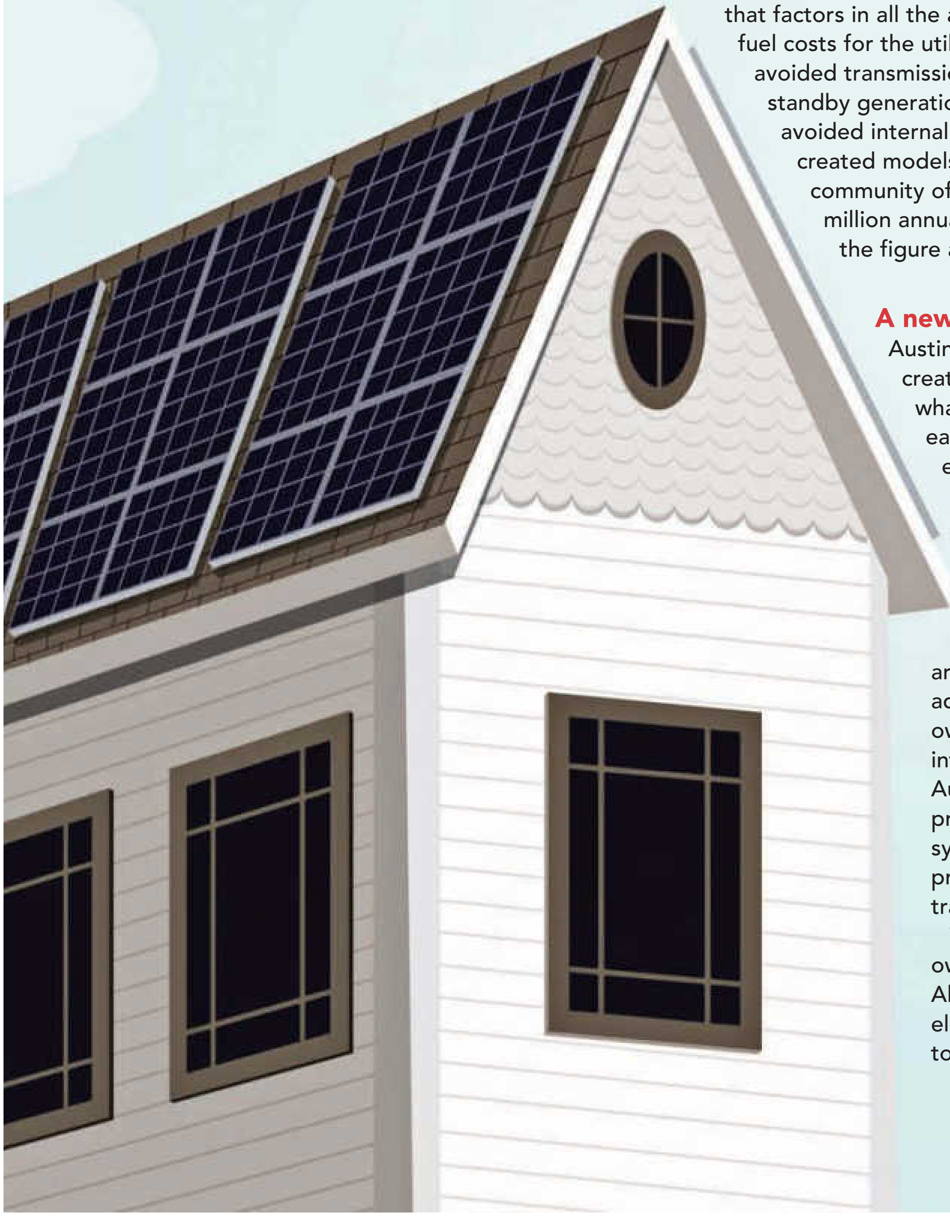


Utilities say solar costs them money

While the net-metering process isn't perfect, it's an effective way to time-shift production by allowing homeowners to "store" electricity on the grid. While there are critics of net metering among both PV supporters and utility companies, the troubling complaint for a prospective solar owner is from the utilities. Some utilities argue that PV customers are essentially free-riders, hopping on and off the grid when it suits them and shifting infrastructure and maintenance costs to nonsolar customers. In at least 20 states, utilities have requested to be allowed to levy additional charges specifically on customers with PV systems. So far, these requests have been rejected. The utilities are responding to a changing business model and declining revenues; as renewable-energy adoption increases, PV owners are not purchasing as much energy from the grid as the utilities predicted. Given the still very low national rate of PV adoption (less than 1% of households), however, the increase in household solar production doesn't account for falling revenue. In fact, data from the U.S. Energy Information Agency shows that electrical consumption has been falling steadily for years because of customers' energy-efficiency improvements.

Solar owners say they're underpaid for surplus

On the other side of the argument, PV owners and many policy advocates argue that net metering doesn't go nearly far enough in recognizing the value of PV to the grid. In places that pay for surplus production, the homeowners are likely to receive the avoided cost, or wholesale rate, for their electricity. Some solar advocates would rather see an accounting method that factors in all the avoided externalities of solar: avoided fuel costs for the utility, avoided greenhouse-gas emissions, avoided transmission costs, reduced need to use and build standby generation, reduced transmission losses, and avoided internalized emission costs. Several studies have created models for calculating the benefits of solar to the community of utility-rate payers. One study found a $92 million annual benefit to California; a similar study set the figure at $520 million annually in Texas.



A new paradigm?

Austin, Texas, and the state of Minnesota have each created an alternative to net metering that uses what's called a value-of-solar approach. In Austin each year, a consulting firm calculates a value for electricity generated by residential solar arrays by creating a price for the avoided externalities. Customers are billed for all of the electricity they consumed from Austin Energy during the billing period, and they receive a credit for all the electricity they generated. In 2015, the solar energy is credited at 11.3¢ per kwh. Excess credits are rolled over each month and don't expire. Minnesota adopted a statewide policy in 2014 requiring investor-owned utilities to offer a value-of-solar pricing tariff. The interesting difference between the Minnesota plan and the Austin plan is that in Minnesota, homeowners (the energy producers) sign a 25-year contract (the expected life of a PV system) with the utility guaranteeing the price for energy produced. The goal is to have utilities pay homeowners a transparent and market-based price for solar energy.

These two value-of-solar schemes are important to PV owners because they incorporate a price for pollution. Also, because the price is more than the wholesale cost of electricity, it undercuts utilities' claims that solar power fed to the grid is worth less.

howitworks

THE MECHANICS OF HOME BUILDING

BY JUSTIN FINK

Ground-source heat pumps

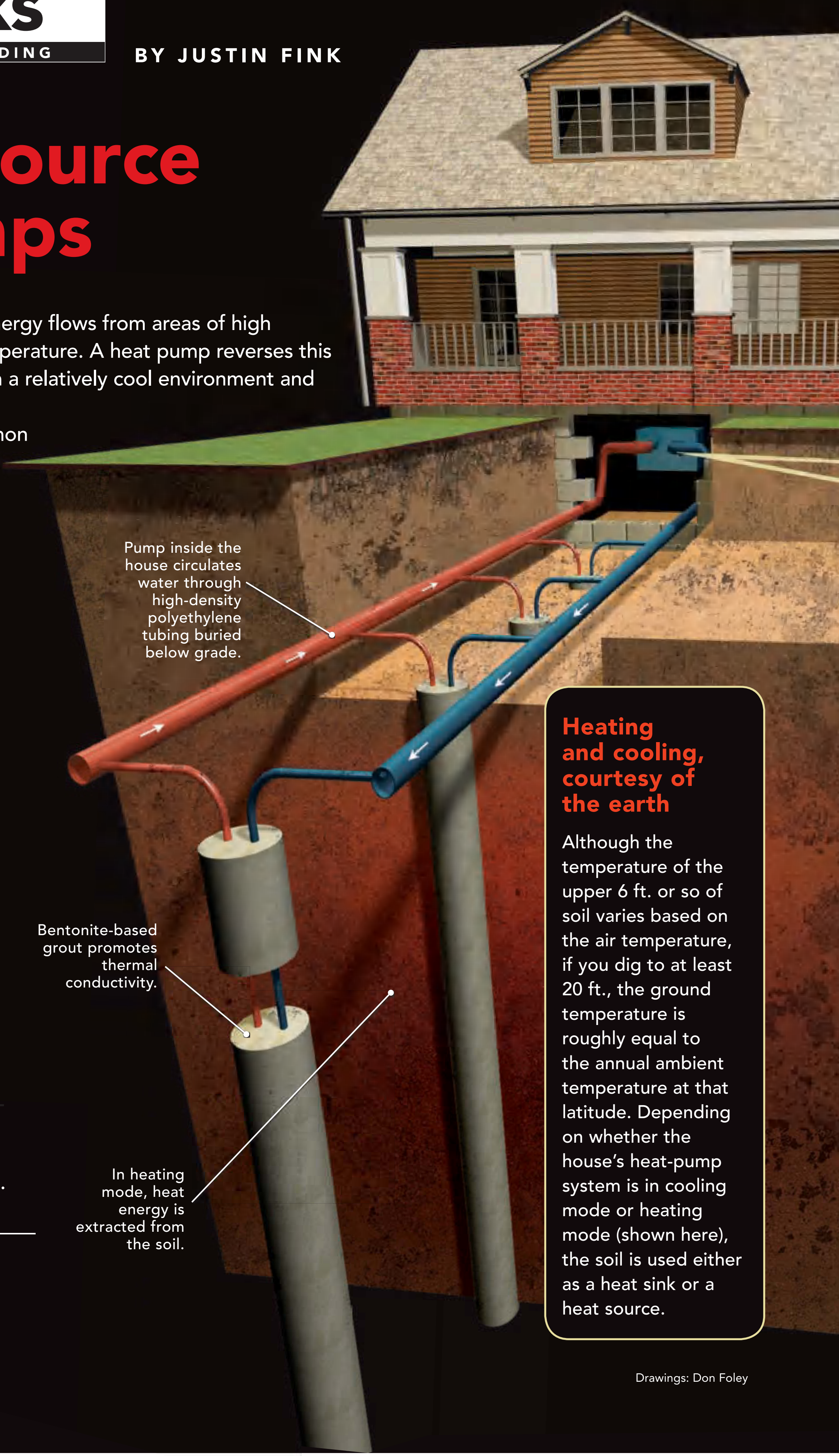
Left to its natural devices, heat energy flows from areas of high temperature to areas of low temperature. A heat pump reverses this natural process, absorbing heat from a relatively cool environment and moving it to a warmer area.

A window air conditioner is a common example of a heat pump. The interior of a room is not cooled by pumping it full of cold air; rather, it's cooled by extracting heat from the room and dumping it outside. A heat pump can also be used to warm a room by reversing the process—that is, pulling heat energy from the exterior air and distributing it inside.

The flaw of air-source heat pumps (ASHPs), the most common type, is that their efficiency decreases with increased temperature extremes. The more frigid the air outside your house, for example, the harder the ASHP has to work to extract usable heat energy. That's why many homes are relying on ground-source heat pumps (GSHPs) for air-conditioning and heating at a higher level of efficiency.

Instead of air, a GSHP uses the relatively stable temperature of the earth as a heat source in heating mode or a heat sink in cooling mode. Here's how it works.

Justin Fink is Project House editor.



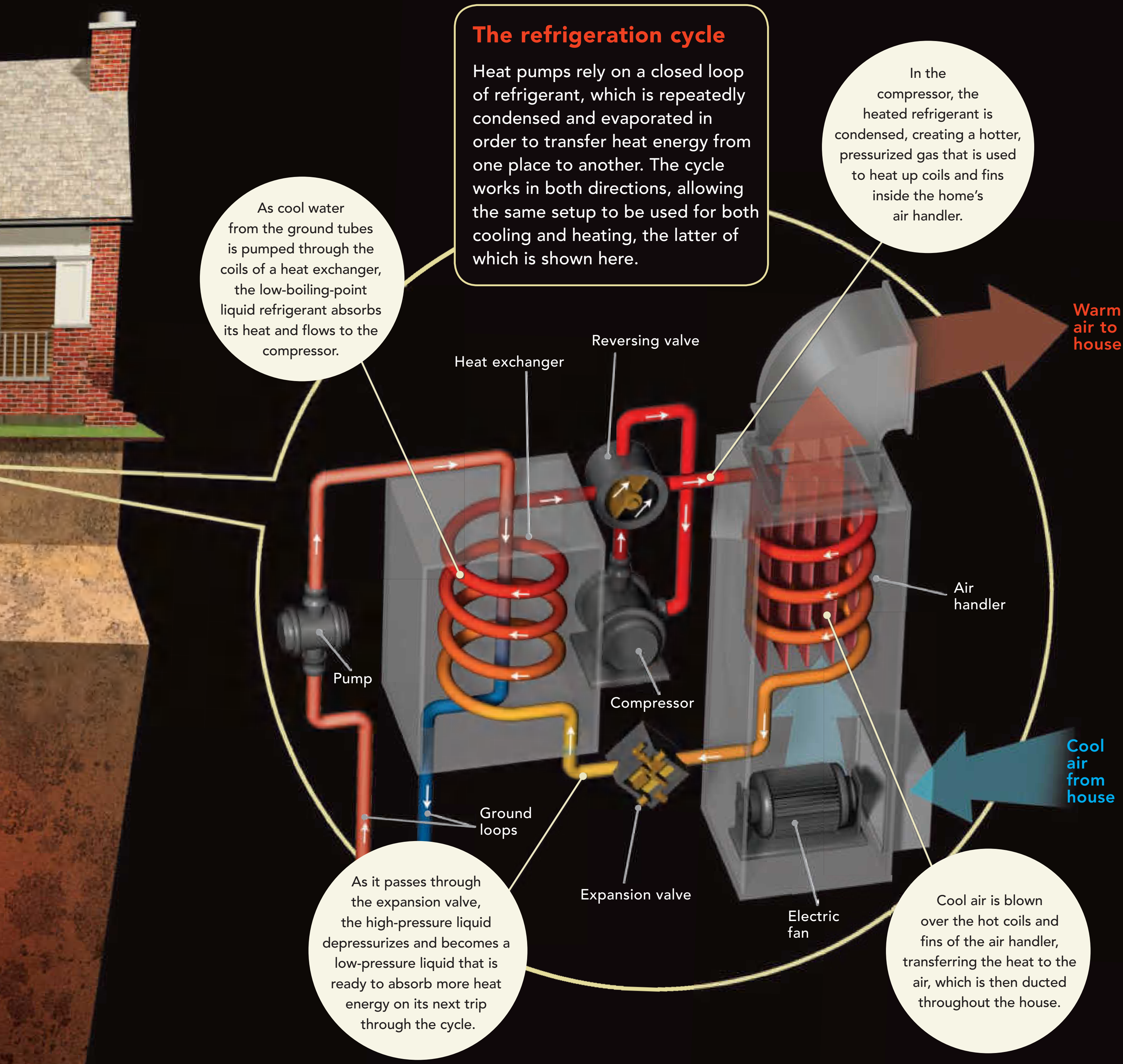
Heating and cooling, courtesy of the earth

Although the temperature of the upper 6 ft. or so of soil varies based on the air temperature, if you dig to at least 20 ft., the ground temperature is roughly equal to the annual ambient temperature at that latitude. Depending on whether the house's heat-pump system is in cooling mode or heating mode (shown here), the soil is used either as a heat sink or a heat source.

Drawings: Don Foley

The refrigeration cycle

Heat pumps rely on a closed loop of refrigerant, which is repeatedly condensed and evaporated in order to transfer heat energy from one place to another. The cycle works in both directions, allowing the same setup to be used for both cooling and heating, the latter of which is shown here.



Loop options aplenty

The layout of the tubing in a ground-source heating system is somewhat customizable and can be changed to suit the site conditions, soil type, and desired heating and cooling load. The tubing may be placed in deep vertical wells from 100 ft. to 400 ft. below the surface, laid out in long horizontal trenches (either in straight runs or overlapping loops), or set below the surface of a body of water.

Photo: courtesy of Idaho Geothermal, idahogeothermal.com

The best of Fine Homebuilding

ENERGY-SMART
Homes

Houses built to save

All-Around

Pairing a proven net-zero strategy with conscious material choices

BY STEVE BACZEK

I see two paths to being green. (I don't like that term, but lack of a better one forces me to use it.) Path 1 is designing a typical code-built house and then applying a degree of recycled materials and site-generated energy in an attempt to make up for building-performance inadequacies. Path 2, my preference, is to integrate performance strategies with scrutinized building practices to develop a house where all the decisions are in harmony with each other. While energy efficiency is always a concern, conceptually I don't solve for it. I concentrate on durability, comfort, and health, making sure to align them with environmental responsibility, particularly in terms of material choices—and then energy efficiency comes along for the ride. The result is a comfortable, healthy home that is durable enough to last a long time, that will remain a high-performance home for decades, and that will have a minimal impact on the environment.

I recently had a great opportunity to design a home in this way with Don and Amy Bowen. If you ask them to describe their lifestyle, you'll hear words such as *simple, environmentally thoughtful, minimalist, uncluttered,* and *free*—which is to say free from a burdened conscience, the trappings of high energy bills, and arduous home maintenance. They live this way in part to have the time and money to pursue their favorite leisure-time activities, but mostly because they are passionate about the fight against climate change.

Photo: Rob Yagid

Efficient

With that philosophy in mind, Don and Amy came to me. Their goals were clear: First, the house had to generate at least as much energy as it consumed. Second, all materials had to be considered for their environmental impact, including both their recycled content and their recyclability. Local materials were to be given the highest priority, and domestically manufactured materials were to be chosen before products from abroad. Third, the house had to strive for a nearly maintenance-free exterior.

The Bowens' passion for this house was personal. They were not interested in a plaque, so I didn't design the house to meet LEED or Passive House or any other standard. Despite that, it is easy to see the influence that the LEED and Passive House standards had on the design. Meeting net-zero energy is a relatively easy concept to succeed at in theory: You build a house, determine the loads, and then design a PV system to balance them out. Although many find it as simple as that, my scrutiny extends a bit further. Developing a net-zero-energy home based only on the economics of energy used/purchased/generated is missing half of the equation. The home's performance should be elevated in an effort to reduce the burden of site-generated energy.

With the generating power of PV panels on the rise and their cost constantly being reduced, net-zero energy is becoming fairly easy

Continued on p. 44

A FORTRESS OF EFFICIENCY

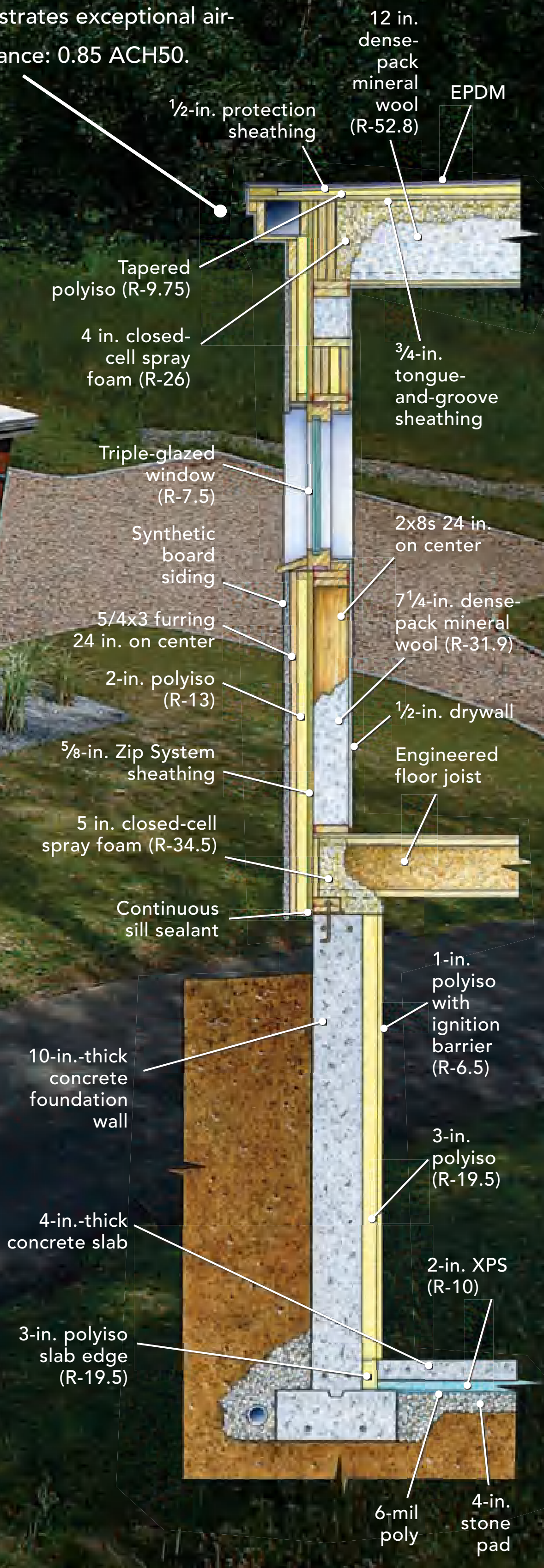
POWERED BY PV The house creates enough energy through its 14.6kw PV system for the house, the studio, and the Bowens' two electric cars. The PV panels are set at 20°, which helps to prevent them from shading each other. The 3.5kw battery system stores excess energy for times when there's no other energy input. The low-slope roof provides a large field for the PV system. Its pitch is a hip-style configuration achieved with tapered pieces (1⁄4 in. per ft.) of rigid polyiso insulation.

DURABLE ENVELOPE
The Bowens wanted a low-maintenance building, so the cladding materials were chosen for their longevity. At the same time, their high recycled content reduces their environmental impact. Firestone Una-Clad aluminum trim coil, made from over 50% postindustrial material, was used for the fascia and soffits. The cladding is a combination of Reynobond, a composite material comprised of aluminum sheets thermobonded to a polyethylene core, and EcoClad XP, a highly durable, nontoxic material made from bamboo and recycled paper bonded together with a corn- and cashew-based resin.

1 Entry
2 Office
3 Powder room
4 Kitchen
5 Great room
6 Porch
7 Dining area
8 Master bedroom
9 Master bath
10 Deck
11 Studio
12 Garage

Photo: Rob Yagid. Floor-plan drawing: Martha Garstang Hill. Drawing facing page: Don Mannes.

A BACZEK WALL ASSEMBLY Basic framing can accommodate the goals of a performance wall. When you don't have to provide special instructions to the framing crew for an exotic wall assembly, that helps with time, energy, money, and accuracy. In all houses the author designs, he strives for exceptional airtightness. The goal of 1.0 ACH50 for this house, while not quite the 0.6 ACH50 of a certified Passive House, still illustrates exceptional airtightness. The final blower-door test revealed even better performance: 0.85 ACH50.



PERFORMANCE MECHANICALS

The house and studio both are outfitted with independent high-efficiency heat pumps, ERVs, and tankless water heaters.

Continued from p. 41

to achieve. That also means it's becoming easier to build a lower-performance house and throw a truckload of PV panels on the roof. While I could meet net-zero energy by building that way, I would not satisfy my basic tenets of shelter, in which comfort, health, and durability play the primary and decisive role in determining the right amount to invest in the home's performance.

Working with Don, who served as general contractor, I developed a Passive House–inspired design that guided us to a high-performance ideal. With the 10/20/40/60/5 insulating rule (R-10 underslab, R-20 basement wall, R-40 above-grade wall, R-60 roof, and R-5 windows) as a guide, I set out to design the building assemblies. The airtightness goal was the high-performance minimum of 1.0 ACH50, which is only slightly above the Passive House standard of 0.6 ACH50.

For health reasons and because we planned to use site-generated electricity, we eliminated all combustibles and agreed to an energy-recovery ventilator (ERV) as part of our mechanical ventilation. For durability reasons, we eliminated thermal bridging and used a cladding system and rain-screen concepts to provide sound water management. Our assemblies were in pretty close alignment with the insulating rule, although because of certain framing-material choices, the R-values for the above-grade walls and the roof deviated somewhat. We also decided to elevate the R-value of the windows. The Bowens wanted a modern-looking house and the above-average amount of glazing that is part of that style. More windows mean less efficiency, however, so the R-5 window value needed to be elevated 150%. The final 10/26/45/88/7.5 design proved to be the best and most cost-effective assembly for lowering the home's energy load.

THREE LEGACIES

Comfort, health, and durability should all be factors in the development of the net-zero-energy equation; actually, there is no excuse for these concepts not to be part of every decision we make in the building industry. They are legacies that will serve the main goal of building a house: to provide shelter that will be around for a long time without being a burden to the environment.

Net-zero energy—a unique challenge every time

The site was purchased in part because of its exposure. It is a large open lot with a tree-filled perimeter. The Bowens wanted from the start to have a low-slope roof, which proved advantageous for integrating a 14.6kw PV system ballasted with blocks to prevent penetrations in the roof. The house is set about 10° off due south to provide the desired views both to and from the house, but that doesn't hamper the PV system's overall production. With a low-slope design, the entire roof can have PV panels as long as none are shading any adjacent panels. This does mean giving up some of the roof area, but what remains still exceeds what would be achieved on half of a gable roof.

The house creates enough energy not only for itself but also for two electric cars. Coupling the PV system with a 3.5kw battery-storage system means that excess energy can be stored for times when there is no other energy input, such as in the evening or during power outages of up to 12 hours. Should the need arise for more storage capacity, extra battery units can be added to the existing system.

Recycled and resourceful material choices

Environmental impact drove all of our decisions. We balanced the presence of recycled content and the recyclability of the home's materials with the durability of those products; if a product has a life twice as long as an alternative, its environmental impact is halved. Flooring is locally sourced or reclaimed. Countertops are largely made up of recycled glass, and water fixtures are low-flow models. Because the Bowens did not want to provide any scheduled maintenance, the cladding materials were chosen for their longevity, and as it turns out, the metal panels and the plank siding have a high recycled content.

Always concentrating on durability, comfort, and health, I aligned environmental responsibility with each concept to ensure that our decisions kept us on the path to shelter that's built to last, which is still the greatest measure of green, whether I like the term or not. □

Steve Baczek is an architect in Reading, Mass.

SPECS

Bedrooms: 1, plus studio
Bathrooms: 3
Size: 2034 sq. ft., plus 320-sq.-ft. studio
Cost: $265 per sq. ft.
Completed: 2015
Location: Hamilton, Mass.
Architect: Steve Baczek
General contractor: Don Bowen

Top photo: David Fell, courtesy of Steve Baczek, Architect.
Bottom photos: left, Aaron Fagan; right, Rob Yagid.

Conscious choices. *The kitchen features an EcoStone recycled-glass countertop and reclaimed beams from a barn in Falmouth, Maine. The flooring, which extends into the master bedroom, is locally harvested hickory finished with a water-based, no-VOC sealer. The glazing throughout the house is triple-pane Yaro windows (below).*

Built on the Past, Designed for the

A new home embraces zero-energy living while respecting its historic neighbors

BY MATTHEW SWETT

A few miles from where I live lies Ebey's Landing National Historical Reserve. It's a soul-stirring place where a hummock of land overlooks farmers' fields as they descend to meet the Salish Sea. I'm struck by the beautiful way in which humans and nature coexist; plowed furrows bending around windswept trees give the sense that human and natural forces have found balance.

This is not by accident. Past residents were so moved by this place that they took steps to protect it. With the National Park Service, they formed the historical reserve—the first public-private partnership of its kind—to look after the character and culture of the community as well as the land itself. Today the reserve extends over 17,000 acres and encompasses the entire community of Coupeville, Washington's second-oldest town. Situated on the protected waters of Penn Cove, the town owes much of its character to the New England sea captains who settled there and left behind elegantly simple buildings. It was here that I was asked to design a new home that would strike a balance between the heritage of the past and the needs of the future.

As if they were always there. *The new house, cottage, and garage match the architecture of Coupeville's historic district more closely than the awkward 1940s structures they replaced.*

Neighborhood friendly—and net zero

My client was a military pilot serving as acting energy manager for the local Navy base. His goals for the house were succinct but comprehensive: It should be well designed and energy neutral, and it should complement the established neighborhood. We agreed that it needed a strong connection to nature through landscaping and an abundance of natural light. I also suggested that the design be easily adaptable to future needs.

Located near the town center, the site occupies a corner lot looking out on Penn Cove and Mount Baker to the north and has unfettered solar exposure to the south. Although

"Before" photo: courtesy of Taproot Architects. Bottom photos, facing page: courtesy of Peter Keyes.

Future

Architecture that blends in *by Peter Keyes*

Ebey's Landing National Historical Reserve contains more than 400 historic structures, with the largest concentration in the town of Coupeville. In the design of this home, it was clear to both Matthew and me that reinforcing the local character was especially important on this site near the town's historic core. Coupeville's 19th- and 20th-century houses express a variety of styles, and the intention was not to mimic any particular one. Rather, it was to enable the new house to fit in with its neighbors through fundamental architectural similarities in scale, form, and detail (photos right).

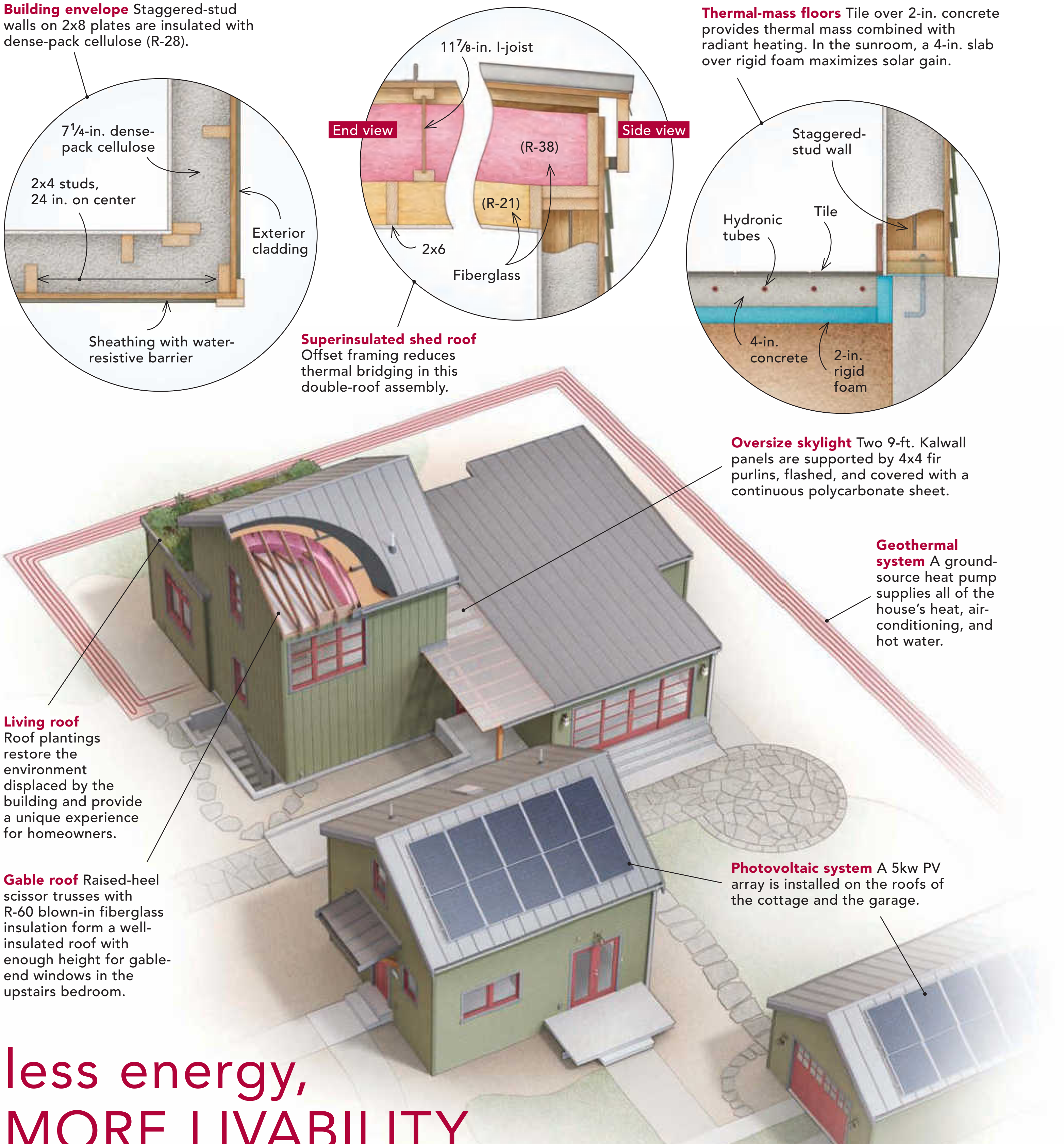
Scale. There are no old mansions in Coupeville; its historic buildings are modest in scale, reflecting their origins on the frontier of the Washington Territory and the ethos of the New England sailors who built them. Here, the design kept the building footprints small by breaking the home into three separate structures.

Building clusters. Perhaps even more important to the character of the town than the details of the buildings themselves, these clusters of buildings tightly interwoven with outdoor areas define spaces in a way that a single building in the middle of a quarter-acre does not. Yards are not hidden behind fences, so passersby get glimpses into the life that goes on there.

Building form. The historic buildings comprise compact, simple shapes topped by steeply pitched roofs (which are hidden by false fronts on the commercial buildings). The new home's design employs three steep gables and a low-pitched roof on the one-story section. This is fronted by flat-roofed bays that recall the commercial blocks nearby.

Simplicity. While the Queen Anne and Second Empire houses in town sport period details, the earlier and vernacular houses have a simplicity in detail and trim that matches their overall form. This simplicity was mirrored with visually traditional materials, understated trim, and clear punched openings for individual windows or small clusters of windows.

Identity. Located on a corner lot, the buildings have facades and doors that address both streets. The rear door of the house may be used more often, but the front door and porch give the house an appropriate formality on the main street and afford a fine view of the cove.



less energy, MORE LIVABILITY

The house met its low-energy goal with a solid envelope and a high-mass radiant-floor system coupled with a ground-source heat pump and a 5kw photovoltaic array. Comfort didn't get shorted, however: An inventive skylight illuminates the interior without sacrificing the envelope, and a bright sunroom puts whatever sunlight there is to good use.

Drawings: Christopher Mills

Sunlight and shelter. *A central patio is sheltered from the wind by the structures around it. Sunlight passing through the south-facing dining-area doors is stored by the thermal mass of the tile-and-concrete floor.*

sandwiched between two historically significant buildings, the structures on this lot were hardly historic. Dating from the 1940s, the flat-topped, vinyl-clad house and cottage had the look of temporary commercial space. The buildings had been neglected for many years and were deteriorating slowly. In fact, the only salvageable parts proved to be their foundations.

No problem with preservationists

New buildings inside the historical reserve require an additional layer of design review, and we faced the process with some trepidation. The regulations had just been updated, and our project was slated to be one of the first reviewed under the new guidelines.

As it turned out, the guidelines were clear without attempting to micromanage design options. While they require new construction to reflect the scale, materials, and massing of their neighbors, they also mandate that it be “stylistically distinct.” This allowed considerable latitude to incorporate elements of traditional Coupeville architecture into a low-energy, contemporary home. Collaborating with me on the preliminary design was Peter Keyes, an architecture professor at the University of Oregon who is also a part-time Coupeville resident and an expert on the town’s historic architecture (see “Architecture that blends in,” p. 47). Our concerns about whether modern sustainable technologies would be accepted by the historic-review committee were quickly laid to rest. Their acceptance of the very visible photovoltaic (PV) panels exemplifies their focus on stewardship and the long-term health of the community rather than adhering slavishly to a fixed vision of the past.

Budgetary constraints also expressed themselves in the home’s design. With much of the budget allocated to sustainable technologies, the materials and detailing were necessarily simple. Rather than introducing layers of ornament or high-cost materials, the project uses the arrangement of the buildings to provide interest. Painted fiber-cement siding proved both inexpensive and complementary to the town’s historic character. Standard vinyl windows were ordered with a painted finish to add a little exterior spice at a reasonable cost. My client’s expertise in energy management allowed us to take full advantage of the latest programs and subsidies available, and the extensive green-building experience of our builder, Cascade Custom Homes, meant that high-performance techniques were already part of the workflow.

Working with the site

Retaining portions of the original foundations meant designing the new buildings on more or less the same footprints as the originals. Concrete contains a considerable amount of embodied energy, so reusing this resource fit with our commitment to a minimal ecological impact. Even with the extent of repairs and structural upgrades required, the reduced site disturbance and material use made the choice worth it.

My client suggested eliminating the cottage, but I convinced him otherwise. When our needs change, we’re often faced with either remodeling our home or moving. I argued that a small cottage can provide the space for a boomerang child, a home business, an aging parent, a tenant, or any number of other functions, thereby taking pressure off the home and its occupants. As it turned out, calculated rental income from the cottage helped meet the bank’s loan-to-value ratio for the property, making it a critical piece of the project.

Though based on the existing foundations, the orientations of the new house and cottage were designed to respond to the climate. With the views to the north and the sun to the south, the buildings loosely encircle a south-facing courtyard, sheltering it from the wind. A south-facing sunroom stores heat in its thick concrete floor, while north-facing windows are placed to maximize views and minimize energy loss. The roofs are pitched to optimize solar gain, while the buildings’ increase in height from south to north minimizes shading of the site.

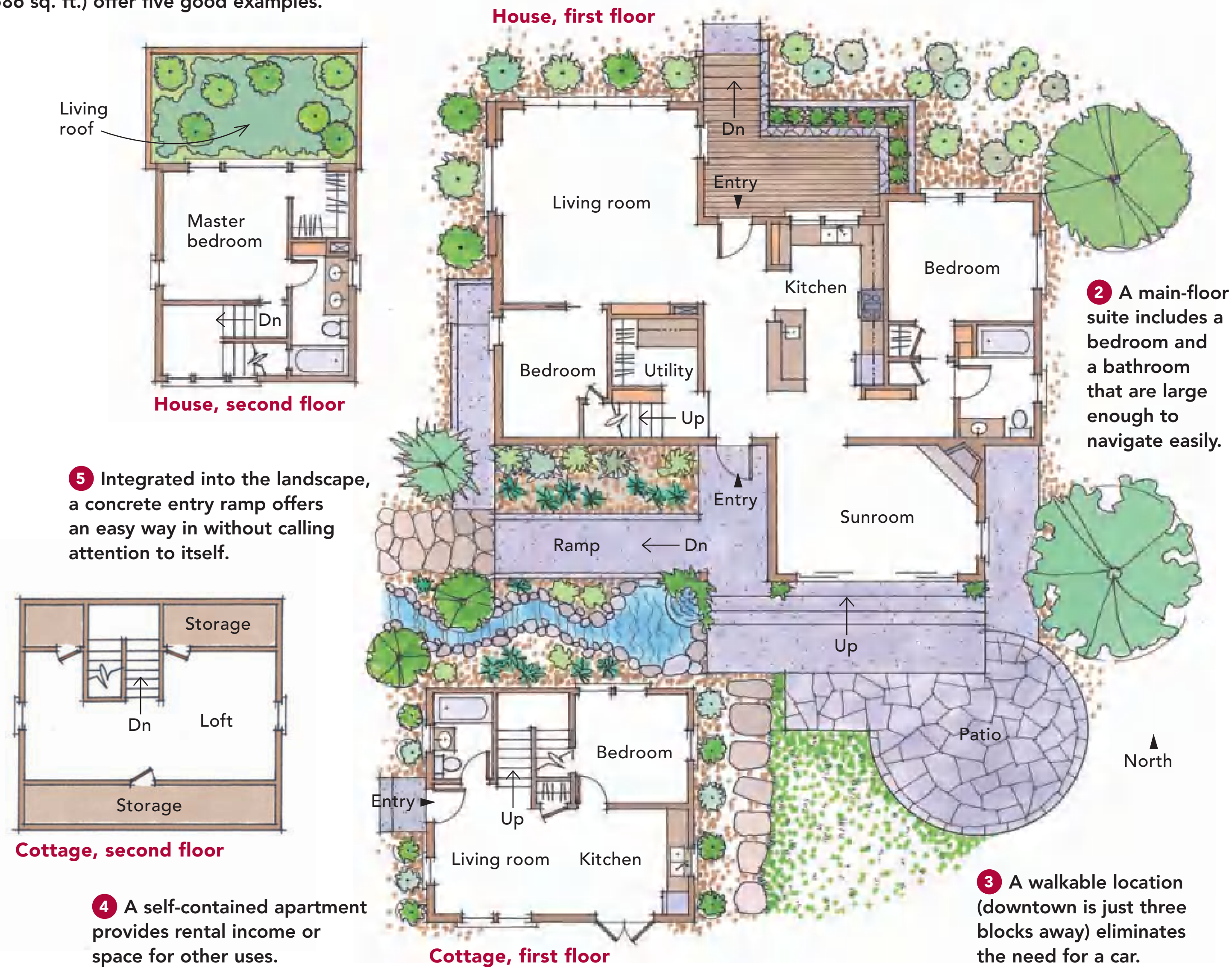
The corner lot presented its own challenge. Coupeville is extremely walkable, and we wanted to present a friendly face on both street fronts. The solution was to provide two front doors, both of which lead to the center of the house. Whether you are coming or going, the layout with the kitchen in the middle makes this feel quite natural.

A multifaceted approach to energy

Even when my clients opt out of formal participation in a green-rating system, I still recommend scoring projects informally to increase their awareness and serve as a

ADAPTABLE and ACCESSIBLE

Creating a home that will stand the test of time includes making it adaptable to its owners' changing needs. With the consent of his clients, the author tries to make every project he designs meet certain minimum standards of accessibility. This house (1698 sq. ft.) and cottage (586 sq. ft.) offer five good examples.



guide in reducing the project's impact on the planet. For this project, we used both Built Green and LEED for Homes as verification tools. The project was officially certified as a 5-Star Built Green home; while we didn't pursue LEED certification, it informally scored at the Platinum level.

Our environmental design strategy was pragmatic and was dictated by Coupeville's relatively mild climate as well as a modest budget. Rather than investing virtually all of our resources in the envelope, as we would for a Passive House, we opted for a systems approach, combining a good envelope (an R-60 roof, 8-in. R-28 walls made with staggered studs, and solid air-sealing) with a high-mass radiant-floor system. In addition to providing comfortable heat delivery, the mass acts as a thermal dampener and evens out the temperature through diurnal swings, cold snaps, and other extreme weather conditions. Instead of spending $50,000 on high-performance windows, we used good, low-cost vinyl windows and applied the $32,000 savings toward the PV array and a ground-source heat pump.

We rounded out the mechanical systems with a heat-recovery ventilator, a drainwater heat-recovery system, and smart thermostats, the latter to provide real-time feedback and data tracking so that my client can monitor the house's performance.

Enabling all of this was my client's tireless pursuit of whatever subsidies he could find for energy-saving features, including the heat pump and the PV panels. By using all Washington-made components, he was able to qualify for the maximum rate by which the electric utility buys back power.

Maximum light, minimum heat loss

Here in the Pacific Northwest, we need as much vitamin D as we can get. That makes me a firm believer in introducing natural light to a home wherever possible. Because

Floor-plan drawing: Martha Garstang Hill

Central skylight. *A supersize skylight built with Kalwall composite panels lights the home's interior without overly compromising the thermal performance of the roof.*

the perimeter windows on this house were generally reduced to match the modest glazing of nearby historic homes, I needed a novel approach. This involved adding a massive skylight at the center of the house, where the interior is typically the darkest.

To accomplish this, I used Kalwall translucent composite panels to create a superinsulated light diffuser. We assembled two 9-ft. panels on-site and then capped them with a continuous polycarbonate waterproofing sheet. Supported by 4x4 Douglas-fir purlins, the result is a beautiful, soft, shoji-like skylight that illuminates the interior and provides R-25 thermal performance.

Despite Washington's wet and rainy image, Coupeville lies in the rain shadow of the Olympic Mountains and receives a scant 21 in. of precipitation a year. With an eye toward someday collecting this rainwater for irrigation, we selected nonreactive metal roofs to prevent contaminants from leaching into the runoff, as well as a living roof to absorb and filter the rain. The roofs are piped to rain gardens for on-site infiltration, with future tank storage planned.

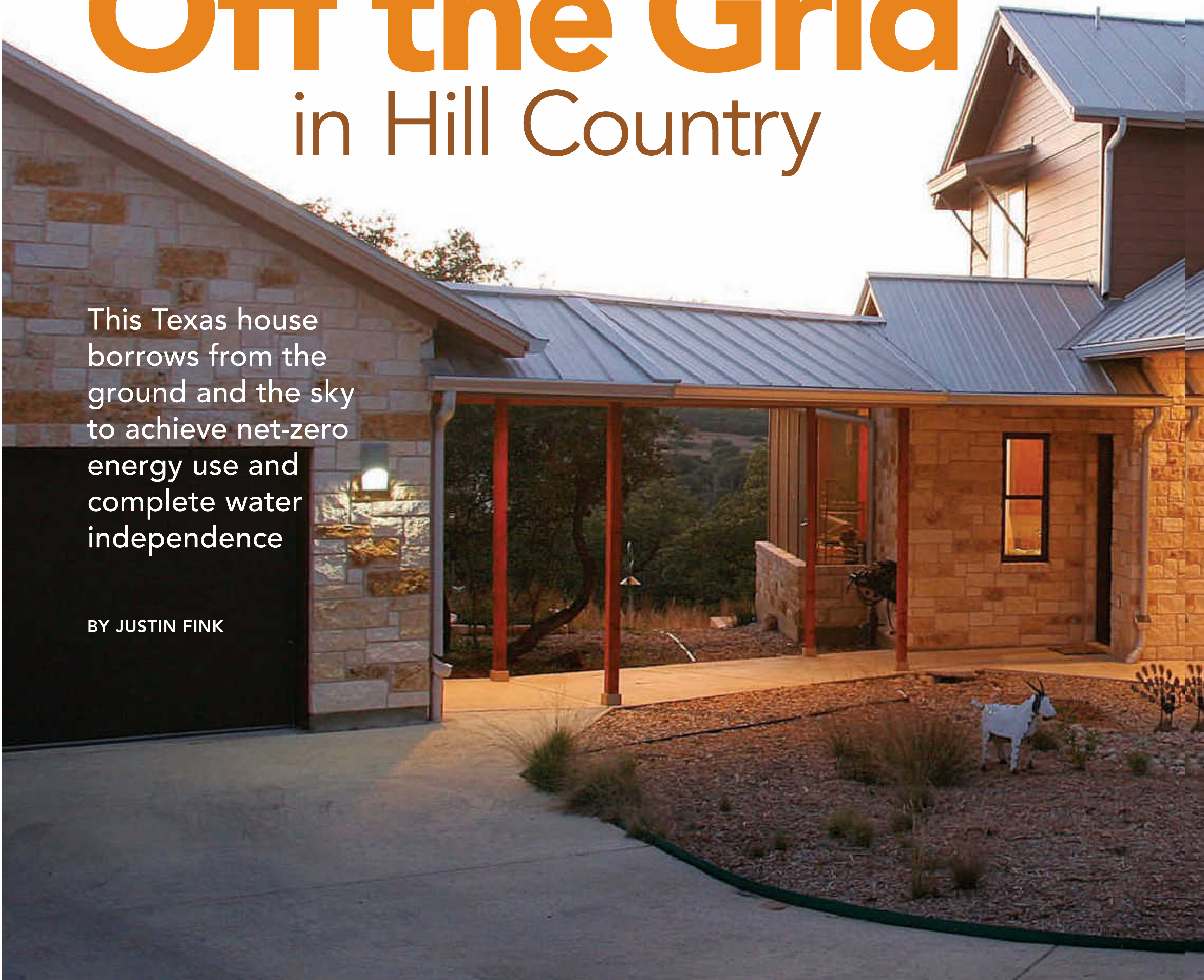
An innovative mounting system for the PV panels clips them to the ribs on the roof, eliminating penetrations and providing plenty of airflow to cool the panels for maximum efficiency. The 5kw PV system required to meet net-zero demands is so large that it covers roofs on both the garage and the cottage. Surprisingly, reserve officials accepted this in a way that typifies their stewardship of this beautiful area's past and its future. As the parks department's staff architect shared with me, preservation requires merging the wisdom of the past with the knowledge of the present. It's this respect for the long view that creates a truly sustaining future. □

Matthew Swett is principal of Taproot Architects in Langley, Wash. Photos by Denis Hill, except where noted.

Stepping Off the Grid in Hill Country

This Texas house borrows from the ground and the sky to achieve net-zero energy use and complete water independence

BY JUSTIN FINK



The real-estate agent's SUV pulled onto a 7½-acre plot and parked on the kind of rocky bluff that you can find only in the Hill Country of Texas. Among the low brush, cedars, and live oaks overlooking a valley with winding roads and a small, distant vineyard, the multiyear search for the right piece of land ended with Peggy's simple declaration: "This is it, Tom. I want to build here." Having entered their third year in their new net-zero home, Tom and Peggy Kolnowski are enjoying the fruits of that long search and subsequent build. The payoff: a house that is not only comfortable and stylish—as at home on the land as its inhabitants are within its footprint—but one that also affords them a nearly off-grid existence.

Powered by the sun above, heated and cooled by the earth below, and quenched completely by the collection and conservation of the sporadic southern rainfall—the house may conjure images of an expensive and painfully complicated endeavor. In truth, the building

Photo: Justin Fink

This project was *Fine Homebuilding*'s best energy-smart home of the year in 2015.

For more information about our annual HOUSES awards, go to FineHomebuilding.com/houses.

costs were only about $175 per sq. ft., and if you ask Tom, he'll shrug and tell you that the whole thing was really pretty simple.

Not unique, but certainly different

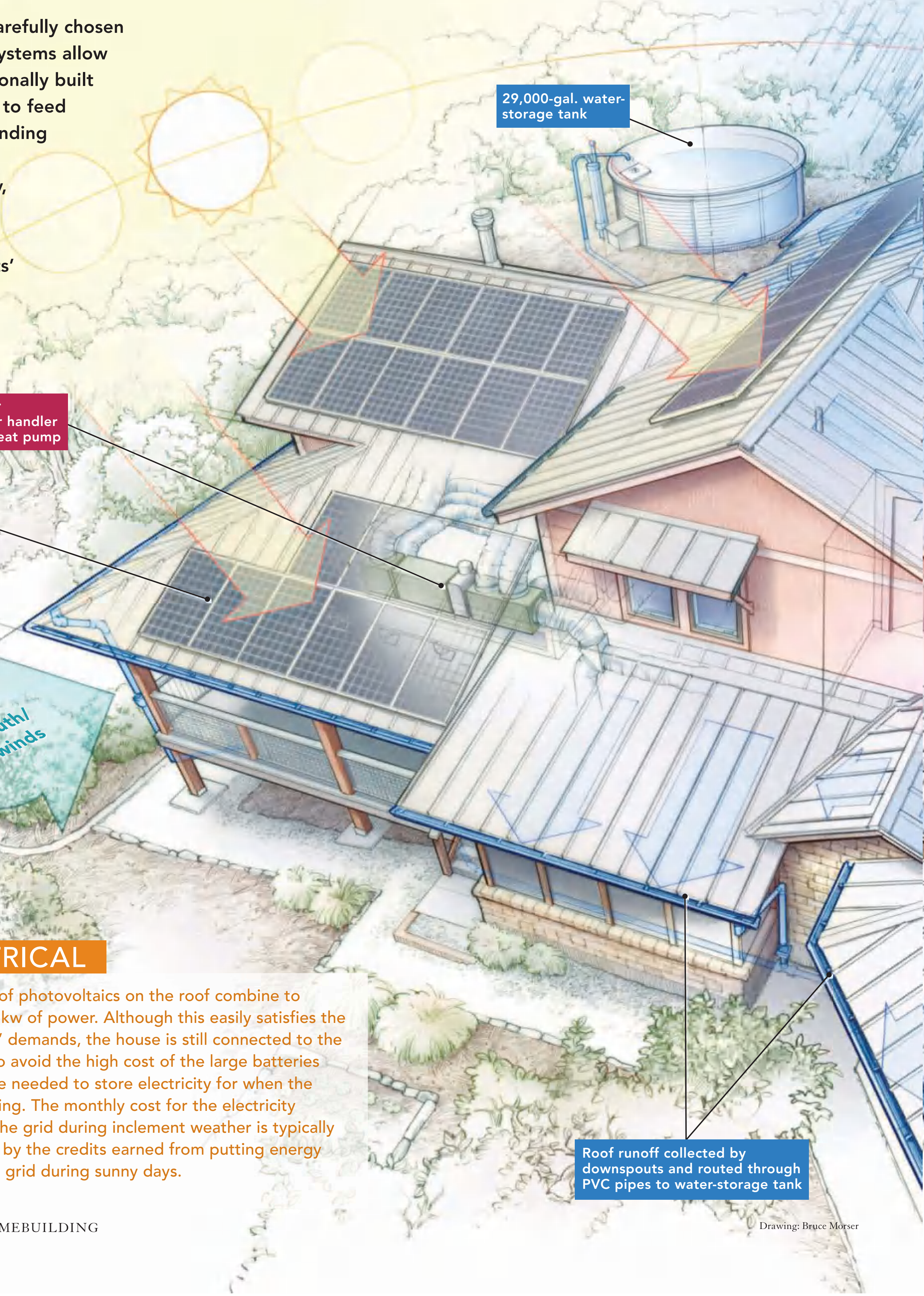
Although this house exceeds the energy standards required by building codes and is advanced compared to the building methods used in mainstream new-home construction, energy geeks and cutting-edge builders would consider its components to be pretty conservative. There are no extrathick walls, excessive amounts of insulation, unconventional uses of conventional building materials, or new-to-market technologies at work here. This architect-designed house isn't constructed much differently than thousands of others, but every component was selected carefully to complete a system.

For the structure of the building, the carpenters used what's known as *advanced framing,* by which extraneous framing lumber is elimi-

Continued on p. 56

POWERED BY THE SUN, CONDITIONED BY THE

A series of carefully chosen mechanical systems allow this conventionally built hilltop home to feed off its surrounding environment for electricity, heating and cooling, and the occupants' complete water needs.



ELECTRICAL

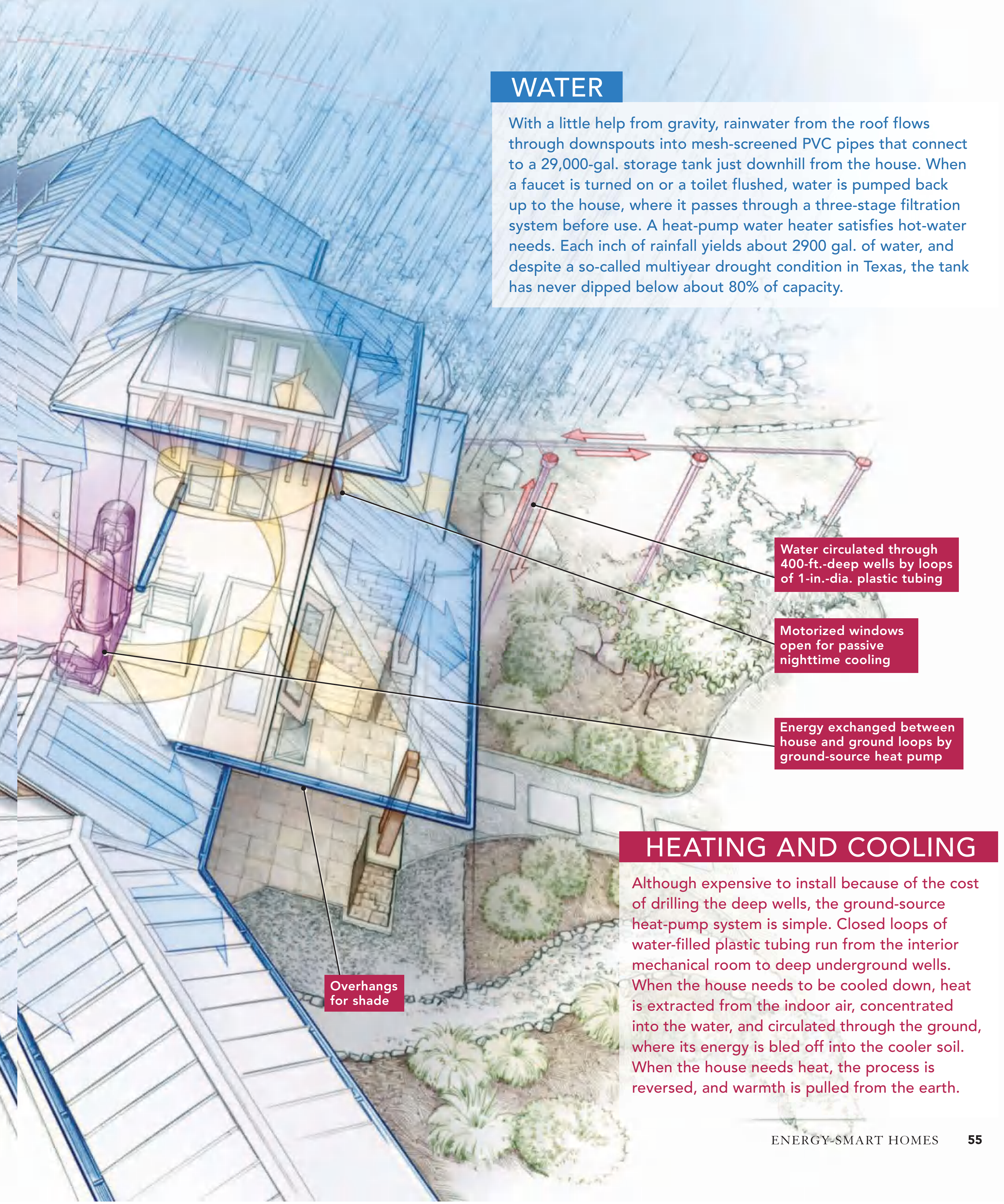
Three banks of photovoltaics on the roof combine to produce 7.75kw of power. Although this easily satisfies the homeowners' demands, the house is still connected to the power grid to avoid the high cost of the large batteries that would be needed to store electricity for when the sun isn't shining. The monthly cost for the electricity pulled from the grid during inclement weather is typically canceled out by the credits earned from putting energy back into the grid during sunny days.

Drawing: Bruce Morser

EARTH, AND QUENCHED BY THE RAIN

WATER

With a little help from gravity, rainwater from the roof flows through downspouts into mesh-screened PVC pipes that connect to a 29,000-gal. storage tank just downhill from the house. When a faucet is turned on or a toilet flushed, water is pumped back up to the house, where it passes through a three-stage filtration system before use. A heat-pump water heater satisfies hot-water needs. Each inch of rainfall yields about 2900 gal. of water, and despite a so-called multiyear drought condition in Texas, the tank has never dipped below about 80% of capacity.



HEATING AND COOLING

Although expensive to install because of the cost of drilling the deep wells, the ground-source heat-pump system is simple. Closed loops of water-filled plastic tubing run from the interior mechanical room to deep underground wells. When the house needs to be cooled down, heat is extracted from the indoor air, concentrated into the water, and circulated through the ground, where its energy is bled off into the cooler soil. When the house needs heat, the process is reversed, and warmth is pulled from the earth.

A truly great room. *The kitchen flows easily into the great room, which is wrapped with windows that provide daylighting, a nice breeze, and a view of the valley and vineyard below.*

Continued from p. 53

nated, creating more space for insulation and less thermal bridging—and thereby reducing heating and cooling costs. In this case, the insulation is open-cell spray foam, which allows the free passage of water vapor but provides better-than-code R-20 heat resistance in the 2x6 walls and R-29 in the 2x6-framed roof. Sprayed directly against the backside of the Zip System sheathing—which has a factory-impregnated air and water-resistive barrier—the house is framed lean, sealed tightly, and insulated well.

The windows are all fairly modest Andersen 100 units, and the doors are from Andersen's Eagle E-Series line. All are outfitted with argon-filled, low-e glass to reflect 95% of incoming UV light, lowering cooling costs further.

With the house's east/west orientation, the screened porch and deep-roofed wraparound back porch provide shelter from the harsh Texas sun while allowing the prevailing south/southwest breezes that blow in from over the valley to provide natural airflow.

To help with nighttime cooling, the house takes advantage of the natural buoyancy of warm air. A stair tower in the foyer extends beyond the second floor and has four awning-style windows outfitted with electric motors that allow them to be opened with the push of a button. With these high windows open, warm air is naturally exhausted and replaced by a cooler stream of air flowing through the first-floor windows and sliding doors. This simple but substantial shell allows the mechanical components to shine.

The systems that make it all possible

In previous decades, setting up the mechanicals in a house striving to meet net-zero-energy requirements meant getting creative with the heating, cooling, electrical, and plumbing systems that were available. There's still a bit of ingenuity necessary these days, mostly because no two houses have the same floor plan or needs, but the components to do the job are now more commonly available, and it's much easier to find contractors who understand the technology.

Although it's operating as part of several integrated systems (see pp. 54-55), perhaps the most technically detailed component in this house is the ground-source heat pump, which provides heating and cooling and helps preheat water to lessen the burden on the water heater. Compared to an air-source heat pump—which loses efficiency when pulling heat from excessively cold winter air and when removing heat from excessively hot summer air—a ground-source heat pump exchanges energy with the earth's soil, where the temperature is a consistent 45°F to 75°F (depending on location and depth) regardless of the season.

Photos this page and facing page: Tom Kolnowski. Floor-plan drawings: Martha Garstang Hill.

Function and flow. *The bamboo-clad kitchen is simple but efficient. A distinct space, it's still connected to the adjacent dining area and the screened porch beyond.*

SPECS

Bedrooms: 3

Bathrooms: 3

Size: 3117 sq. ft.

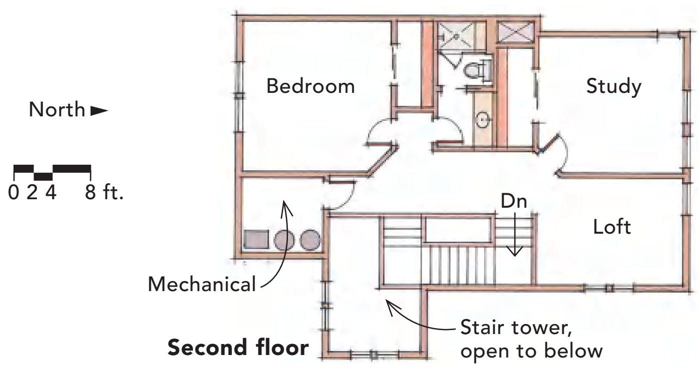
Cost: $175 per sq. ft.

Completed: 2013

Location: Driftwood, Texas

Architect: Donovan Davis, Danze & Davis Architects, danze-davis.com

Builder: Lloyd Lee and Jonathan Clow, Native, buildnative.com



To increase the inherent and already impressive efficiency of the ground-source heat pump, the Kolnowskis are powering the system with photovoltaic panels, which provide the energy for their heating-and-cooling system for a fraction of what it would cost if it were to run on conventional metered electricity.

The photovoltaics are the big push that sets the house apart from the crowd. In addition to the Austin Energy Green Building (AEGB) five-star rating—the highest level of award available in the program—the Kolnowskis' home earned a Home Energy Rating System (HERS) Index score of 7, which is far better than the average score of 100 for new homes.

The all-electric home is performing very close to its near net-zero-energy design spec, with an average utility bill of about $20 per month, much of which simply represents the cost of maintaining a connection with the power grid.

That view through the windshield on their very first visit to the site is now Tom and Peggy's view from the great room of their dream home: a hillside retreat that is every bit as personalized and comfortable as they imagined, with the added benefit of being nearly self-sufficient. □

Justin Fink is Project House editor.

A Pretty Good

What is a PRETTY GOOD HOUSE?

By Jesse Thompson

A lot of attention is being paid to ambitious building-certification programs. For energy conservation, Passive House is the gold standard, but there are many other competing programs that all attempt to define what "the best" might be. Then there's Pretty Good House (PGH).

This building program isn't a program at all; in fact, its founders have resisted any attempt to codify, market, exploit, or monetize their creation beyond a few blog posts. If the concept remains a bit nebulous, the creation story isn't. The concept grew out of the Building Science Discussion Group in Portland, Maine, which is a monthly gathering of contractors, architects, engineers, energy raters, and product suppliers who have been meeting since 2009 to hash out the potential pitfalls and best practices of construction. Dan Kolbert, Mike Maines, Steve Konstantino, and Chris Briley are the individuals generally credited with pushing the rough outline of what a Pretty Good House in this era would look like and what makes sense in terms of efficiency, budget, timetable, etc.

PGH has jelled around a set of complementary building practices and components. These include using local, low-embodied-energy products; testing a house after construction is complete to

House in Maine

This home's low energy bills speak louder than any performance certificate

BY STEPHEN SHEEHY

Like many people approaching retirement age, my wife and I decided that it was time to downsize. At more than 4000 sq. ft., our home of 22 years was much too big for us. We selected a building site alongside our existing house in Alna, Maine, a small town of 700 people near the coast, that offered views of a small pond and fields beyond.

I'd done a lot of research into modern building practices and materials, and I wanted our new house to be cheap to operate and easy to maintain—while also being nice to look at and to live in.

Lots of organizations will certify a house based on whether it meets particular standards for efficiency, including LEED, Energy Star, and Passive House. While these certification programs have aided in the development of technologies and construction processes and spurred the creation of many new products, certification itself comes at a significant financial cost. Someone needs to be paid to certify that the claimed efficiencies have been realized, and it may be necessary to spend extra money to meet the standard, even though some expenses may not be recouped through energy savings.

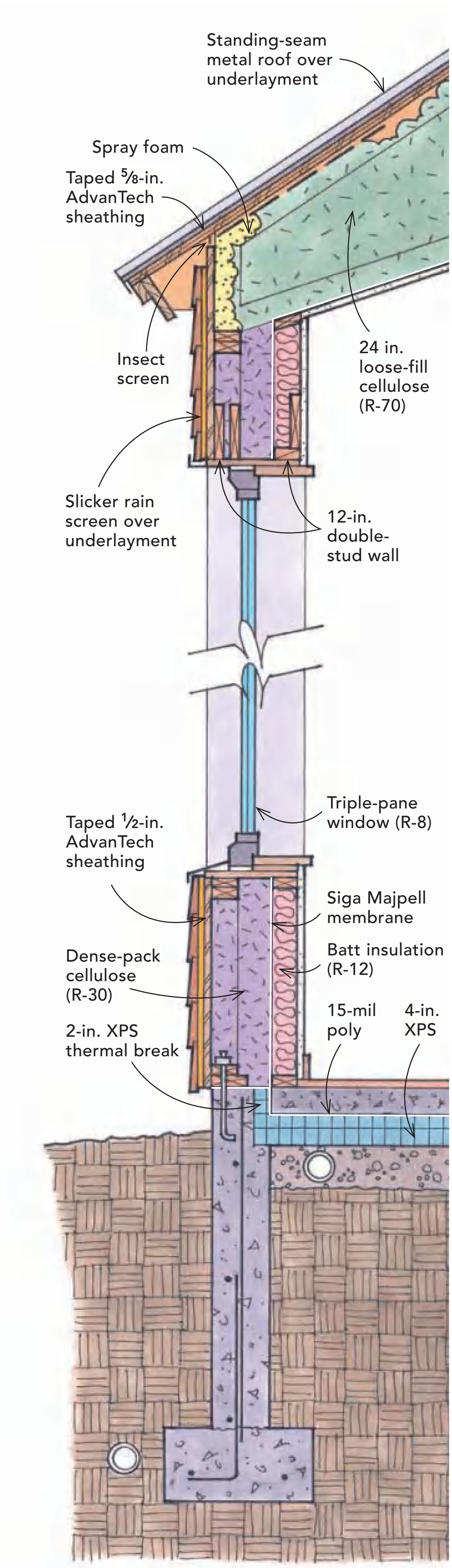
Certification certainly didn't make sense in our case, mostly because we were not building for resale. And even if we were, I felt that a history of low utility bills would

Continued on p. 63

ensure that it's performing as designed; installing a fresh-air ventilation system to go along with good air-sealing levels; insulating to Building Science Corporation's recommended 5-10-20-40-60 levels (in climate zones 5 and 6); using triple-glazed windows; and designing a house that can probably be net-zero energy with a PV array on the roof. There are no required calculations, no paperwork, no plaques.

One fascinating aspect of this approach is that your goals end up being defined by other people's efforts. If PGH aims always to be close to what's considered the best, then when someone else moves the marker, PGH follows them along the path. We've seen this with air-sealing in the past decade. While 3 ACH50 to 5 ACH50 became the standard for Energy Star and building codes, Passive House moved the bar to 0.6 ACH50. As a result, it takes 1.5 ACH50 to reach PGH.

We will probably never know how popular the PGH concept ends up being. There will never be a nationwide database of certified projects, no grand headquarters in Washington, D.C., and no annual trade show in Las Vegas. Instead, there will be happy homeowners near and far with low energy bills and comfortable houses, all living a pretty good life.



Anatomy of a **PRETTY GOOD HOUSE**

In a nutshell, the PGH approach is about finding the sweet spot between the cost and benefits of energy-efficiency measures. The originators of the concept list 23 distinct characteristics that identify a Pretty Good House. Several of those as exhibited by the Sheehys' house are described here.

Near net-zero

The 6.5kw of solar panels on the roof should generate about 8000kwh per year, roughly equal to what the author expects to use, although initial use so far has been lower than expected.

No fossil fuels

The house is 100% electric. Heating and air-conditioning are provided by a pair of Fujitsu RLS3H minisplits (9000 Btu and 12,000 Btu), with additional radiant heat under the bathroom tile. Although a heat-pump clothes dryer was chosen for its efficiency and to eliminate a vent that would impact the building envelope, a conventional electric-resistance water heater made better sense for a single-level dwelling; plus, it's quieter than a heat-pump model. Cooking appliances include an induction cooktop and an electric convection oven.

Adaptability, durability, and recyclability

On the exterior, both the standing-seam metal roofing and the unfinished white-cedar shingles require little maintenance. Inside, a polished concrete floor is scratch resistant, is easy to maintain, and stores heat when the sun shines through the south-facing windows. Recycled materials include 4-in.-thick foam (greeninsulationgroup.com) under the slab.

Air leakage capped at 1.5 ACH50

Air leakage in the house was minimized by taping sheathing and housewrap and by limiting penetrations through the building envelope. A blower-door test measured 0.59 ACH50, meeting Passive House standards. Airtightness was

enhanced with Siga Majpell membrane behind the ceiling drywall and inside the walls, and windows were sealed with Siga Wigluv tape.

Service core for plumbing and wiring
Flat ceilings on the north side of the house create room for a utility chase between the ceiling and the roof trusses that is accessible through a hatch. Almost all wiring and plumbing are on the conditioned side of the building envelope. The only exceptions are the lines for outdoor lights, outdoor receptacles, and hose bibs. These and the other penetrations through the envelope—for the plumbing vent, the HRV's intake and exhaust, and the lines for the two minisplits—were air-sealed carefully.

5-10-20-40-60 insulation rule (windows, slab, foundation, walls, roof)
Built atop an insulated slab (R-20), the double-stud walls (R-42) combine dense-pack cellulose and fiberglass batts and have high-performance Intus windows (R-8). The roof is framed with raised-heel scissor trusses, which allow for an insulated cathedral ceiling (R-70).

Good design and a simple structure
A single-story, relatively open floor plan makes for easier heating and cooling, and most of the glazing faces south, which allows for significant solar gain, especially when the sun is low in the sky in winter.

Mechanical ventilation
A Zehnder ComfoAir 200 HRV in the mechanical room brings 72 cfm of fresh air into the bedroom, den, and great room, and it expels spent air from the bathrooms and kitchen. A boost switch in the master bath can be activated to remove humidity when someone is running the shower.

Universal design
The house has wide doors with lever handles, no stairs, and a curbless shower to make accessibility and aging in place possible.

SPECS

Bedrooms: 2

Bathrooms: 1½

Size: 1860 sq. ft.

Cost: $242 per sq. ft.

Completed: 2015

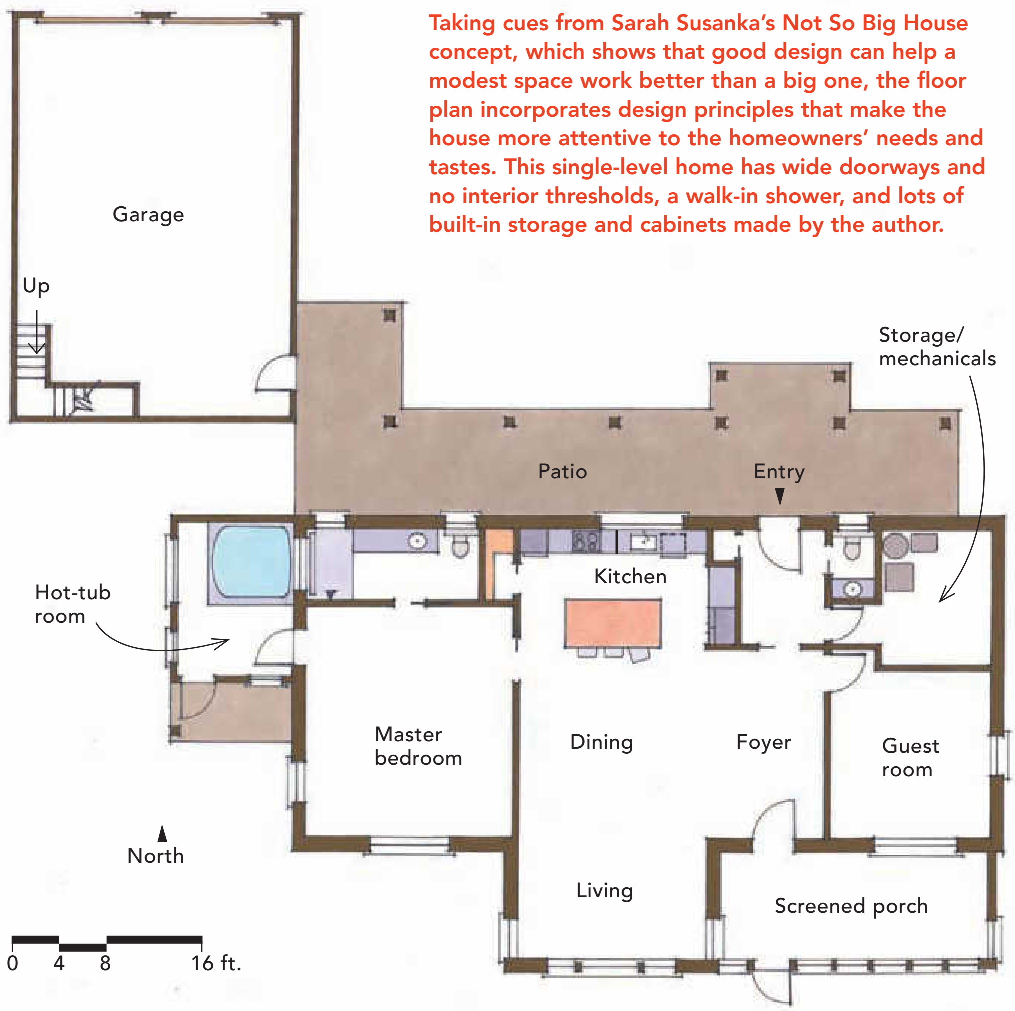
Location: Whitefield, Maine

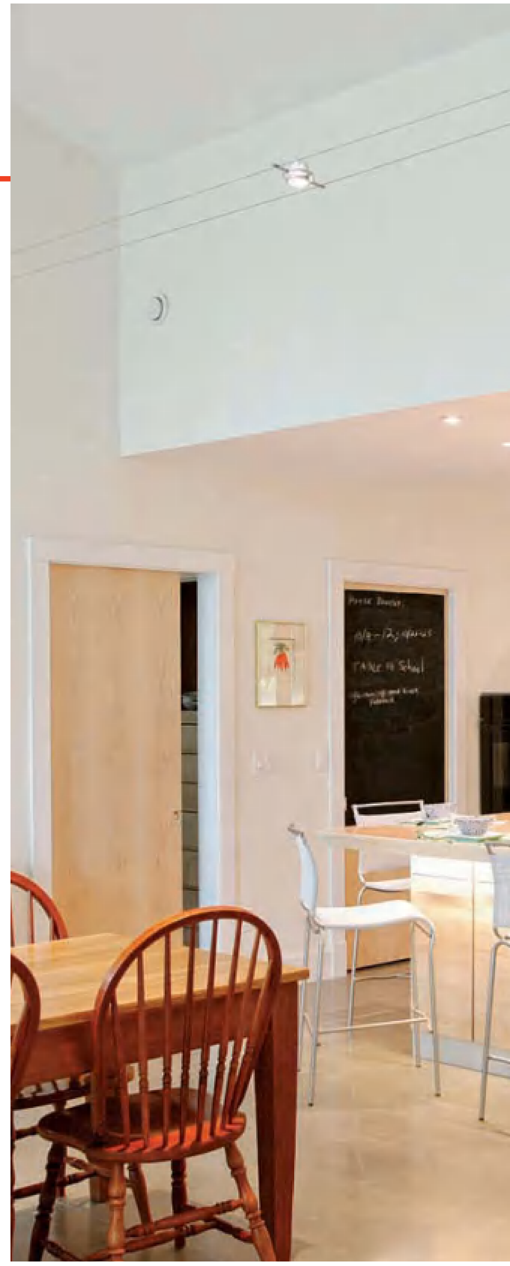
Architect: Kaplan Thompson Architects, kaplanthompson.com

Builder: Tom Greenleaf, greenleafbuilding.com

A LOOK INSIDE

Taking cues from Sarah Susanka's Not So Big House concept, which shows that good design can help a modest space work better than a big one, the floor plan incorporates design principles that make the house more attentive to the homeowners' needs and tastes. This single-level home has wide doorways and no interior thresholds, a walk-in shower, and lots of built-in storage and cabinets made by the author.





Passive solar. *The south-facing, triple-glazed Intus windows are Passive House certified, and the low-maintenance concrete floors store heat from the sun.*

***Service core.** Flat ceilings on the north side of the house create room for a utility chase that keeps almost all wiring and plumbing within the house's conditioned space.*

Continued from p. 59

make a stronger case to new buyers than a paper certificate. Ellin and I had heard about the Pretty Good House (PGH) concept, and we were intrigued with the sensible approach to construction it entails (see "What is a Pretty Good House?" p. 58).

The Pretty Good path

To guide us in designing our PGH, we selected architect Jesse Thompson of Kaplan Thompson Architects in Portland, one of the originators of the concept, because I had read about Jesse's work at GreenBuildingAdvisor.com. For our contractor, we chose Tom Greenleaf, who had done various small projects with us since building an addition on our former house about 10 years ago. We found Tom great to work with, highly skilled, and intrigued with our ideas.

Armed with a basic floor plan and a list of needs, wants, and don't wants, we met with Tom, Jesse, and Jamie Broadbent, also of Kaplan Thompson Architects. We discussed a single-level home with wide doorways and no interior thresholds; a walk-in shower; lots of built-in storage and cabinets, which I would build myself; a low-maintenance exterior with clean, simple lines; and a covered entry. We also wanted lots of windows to take advantage of the view. Most of all, we wanted the new house to be energy efficient. Energy costs in our previous home had been as high as $6000 annually, a financial burden we did not wish to continue.

We've long been fans of Sarah Susanka's Not So Big House concept, which focuses on quality, not quantity, and recognizes that good design can help a smaller home work better than a big one. Susanka suggests establishing a budget and then focusing not on maximizing square footage but on using features such as built-ins, ceilings of various heights, and interior details to make a house more attractive and user-friendly. These features, it turns out, were right in line with our vision of a PGH.

Modeling, with moderation

Once we had established our basic design parameters, Jesse and Jamie used the Passive House Planning Package (PHPP) modeling software to analyze the impact that various changes in design would have on energy use and cost. Among those variables is airtightness. The Passive House standard for airtightness is 0.6 air changes per hour at –50 pascals (ACH50), which is much lower than that allowed by the most stringent building codes. We figured we would aim for that and be happy if we got reasonably close. But when our initial blower-door reading came in at 0.8 ACH50, we got caught up in the challenge of driving it down further. The blower-door technician cranked up the blower again and, armed with canned foam and Siga tapes, we went looking for air leaks. We found and plugged a few, which helped us eventually reach an airtightness of 0.59 ACH50.

Taking the best, leaving the rest

At Jesse's suggestion, we looked at Intus windows and doors and were impressed at the robust construction and terrific performance numbers. Their cost was competitive with windows from larger, better-known companies. We ended up using their Passive House–certified, triple-pane windows throughout the house, except on the sunporch and hot-tub room, both of which are outside the conditioned space.

At the same time that we chose to pull out all the stops to maximize airtightness, our PGH approach allowed us to skip unnecessary and expensive refinements designed to squeeze that last bit of efficiency out of the project. For example, we knew that 4 in. of foam under the slab would save a good deal of heating energy and enhance comfort but that increasing the amount to 10 in. or more, as is typical in a certified Passive House, was unlikely to be worth the extra several thousand dollars.

Our new home is comfortable and was cool over the summer, and we expect that it will be plenty warm this winter. It's also nice to look at, is easy to clean, and promises to require minimal maintenance. It's a pretty good house, indeed. □

Stephen Sheehy built his own house many years ago and spent a few years as a carpenter before attending law school. Photos by Debra Judge Silber.

BY DEBRA JUDGE SILBER

Radiant barriers

Want to get builders into a heated discussion? Bring up radiant barriers.

Promoted as a method for reducing cooling costs by mitigating solar heat gain through walls and attics, these shiny (typically aluminum) surfaces have as many detractors as proponents. The dispute is not about the science of radiant-heat transmission; it's whether applying that science to your roof will make a difference on your utility bill.

FIRST, THE SCIENCE

Heat energy moves through houses (and everything else) in three ways: conduction (when objects touch), convection (through air movement), and radiation (through an airspace or vacuum via electromagnetic waves). Insulation, thermal breaks, and air-sealing prevent conduction and convection; radiant barriers prevent heat transfer through radiation only.

Emissivity (or emittance) measures how much radiant energy a material emits. It's rated on a scale from 0 to 1; the lower the value, the less energy emitted. Radiant barriers by definition have an emissivity of 0.1 or less, emitting 10% or less of the radiant energy striking them.

DO THEY RADIATE OR REFLECT?

Both, actually. Surfaces that are highly reflective to long-wave (heat) energy are also low-emitting. Aluminum, for example, reflects 97% of the long-wave radiation that hits it, emitting 3% into the airspace on the other side. Remember, though, we're talking about invisible, long-wave radiation—not visible light. White paint, for example, does a great job of reflecting light but a poor job of blocking long-wave heat transfer. The key point is this: A material can look reflective and not be a good radiant barrier, and a good radiant barrier will work whether or not the shiny side is facing the heat source—as long as it is facing an airspace.

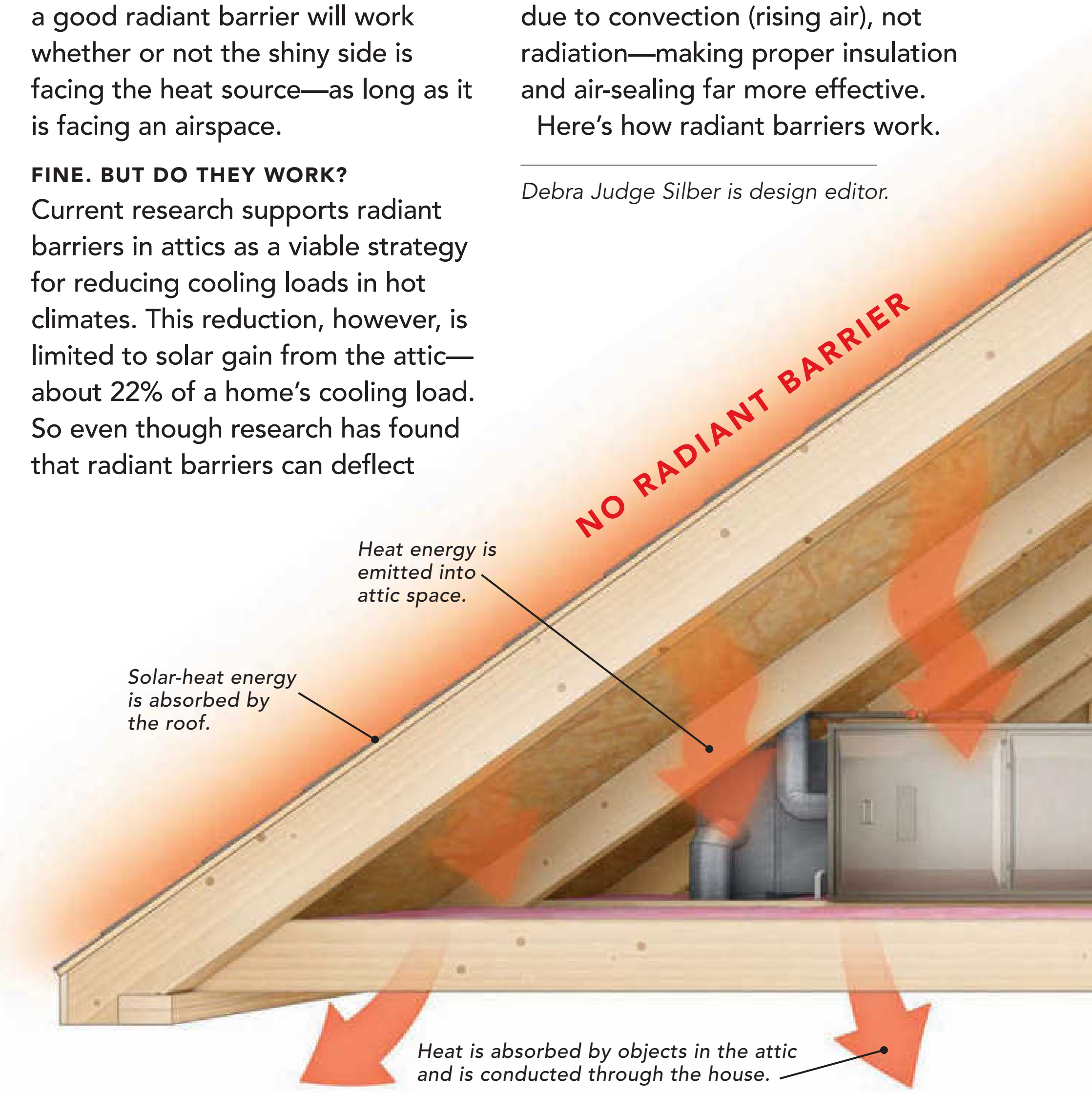
FINE. BUT DO THEY WORK?

Current research supports radiant barriers in attics as a viable strategy for reducing cooling loads in hot climates. This reduction, however, is limited to solar gain from the attic—about 22% of a home's cooling load. So even though research has found that radiant barriers can deflect 40% of incoming attic heat, the net savings represents only 8% to 10% of a home's total cooling costs.

The benefit is even sketchier in northern homes, where summer heat gain is less of a concern and the barriers may limit beneficial winter solar gain. Although radiant barriers may help to retain winter heat, most winter heat loss through attics is due to convection (rising air), not radiation—making proper insulation and air-sealing far more effective.

Here's how radiant barriers work.

Debra Judge Silber is design editor.

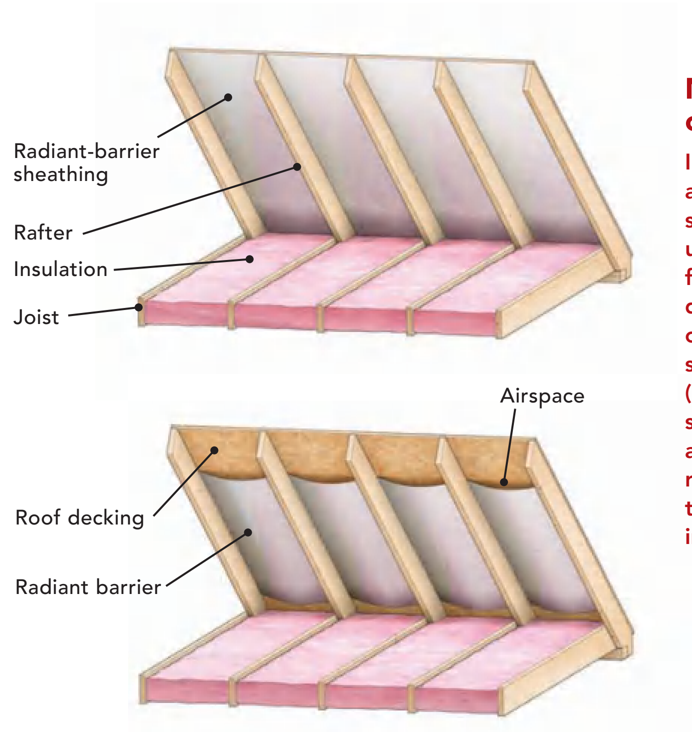


Drawings: Christopher Mills

WHERE RADIANT BARRIERS WORK—AND WHERE THEY DON’T

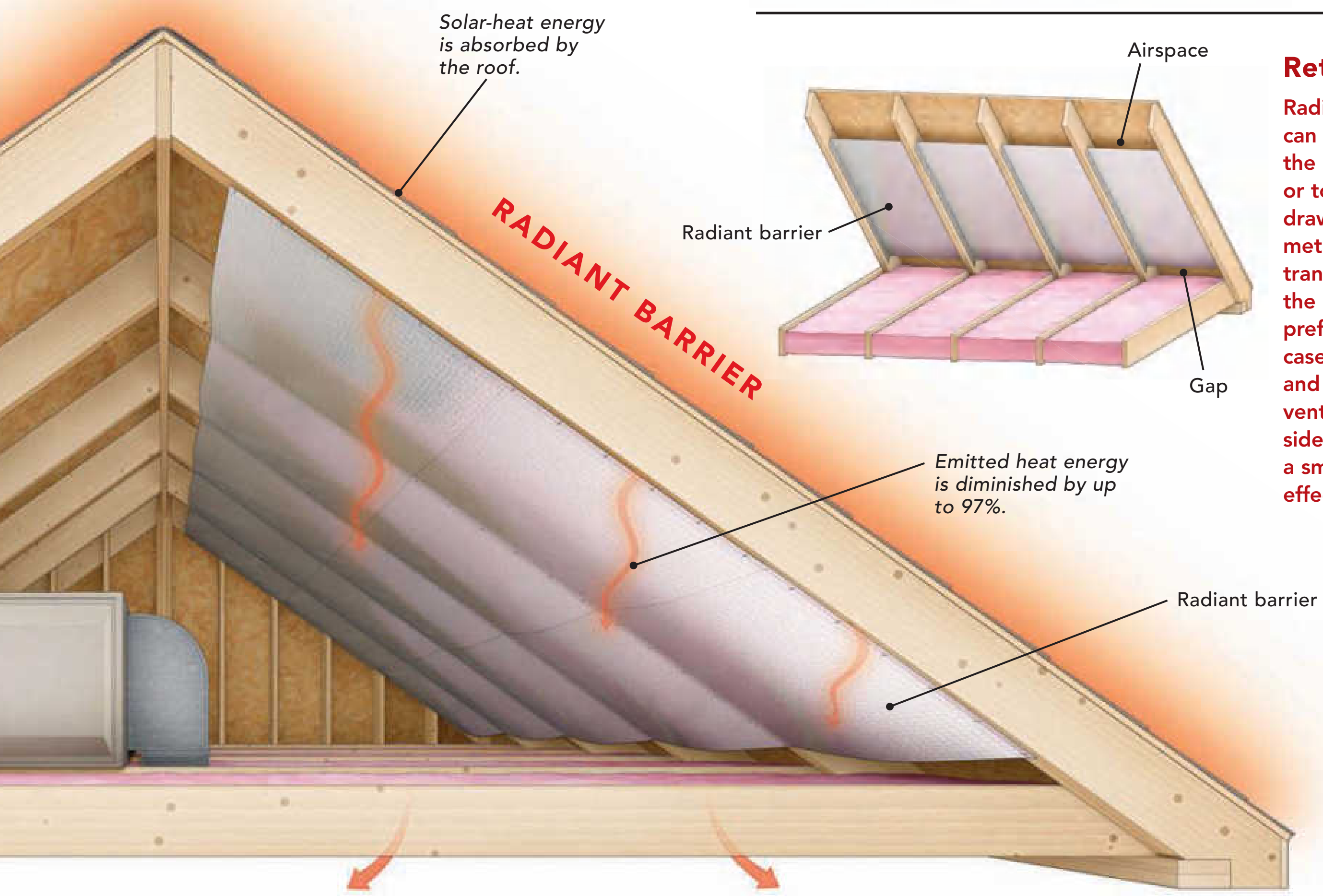
Because radiation occurs in an airspace, radiant barriers won’t work unless they face an airspace. If pressed between two surfaces, a radiant barrier becomes a heat *conductor*. In addition, because heat moves toward cold, there also must be a difference in temperature between materials. Radiant barriers, then, are of negligible benefit in well-insulated homes.

Vented attics can be good places for radiant barriers because they contain large airspaces and take the brunt of solar-heat gain. Because walls are subject to less solar gain and because heat transfer through them relies more on conduction and convection than radiation, radiant barriers in walls provide less benefit. Although barriers placed on attic floors can work, surface dust will eventually hinder performance.



New construction

In a new vented attic, radiant-barrier sheathing can be used (top left), or a foil barrier can be draped over the rafters or trusses before sheathing is installed (below left). In the second example, the airspace created in the rafter bays enhances the foil’s effect by increasing ventilation.



Retrofits

Radiant-barrier foil can be attached to the rafter sides (left) or to the faces (large drawing). The latter method curtails heat transfer through the rafters and is preferred. In both cases, gaps at the top and bottom promote ventilation. Double-sided foil provides a small increase in effectiveness.

Sources: Florida Solar Energy Center; Oak Ridge National Laboratory

Photo: Rodney Diaz

Products that perform

Mineral Wool Makes a Comeback

This natural spun-stone insulation is enjoying a resurgence in popularity—and for good reason

BY MIKE MAINES

Mineral-wool insulation has been in use since the late 1800s, so it's nothing new. But as the market shifted in the 1960s to less-expensive and better-promoted fiberglass insulation, the mineral-wool industry shifted its focus to industrial and manufacturing applications, where mineral wool became a perfect replacement for the asbestos materials being phased out due to health concerns. Yet over the last 25 years, the cost of energy, the public's awareness of health and environmental impacts, and building-science research have led to a renewed interest in mineral wool for the residential market also.

It's not hard to see why mineral wool is regaining lost ground. It's got an R-value of 3.8 to 4.3 per in., it's chemically inert, it contains almost no VOCs, it's fireproof, it absorbs sound, and its embodied energy is lower than that of most petroleum-derived foams. Sold most commonly as batts, it's also available as boards and as loose fibers for blown installations, and it can be used in all the critical locations: walls, floors, ceilings, roofs, exteriors, and even below grade. It is vapor permeable—which has its disadvantages as well as its advantages—and is fairly easy to install well. In a category that has long been dominated by fiberglass batts, mineral wool is worth a fresh look.

Mike Maines is a residential designer in North Palermo, Maine.

THE OPTIONS LOOK FAMILIAR

BATTS

Mineral-wool batts come in widths and thicknesses typical for residential construction, but only in 48-in. (or sometimes 47-in.) lengths, and never in rolls. Batts are formed slightly wider than typical 16-in. or 24-in. framing cavities to create a tight friction fit, and they don't move or change significantly over time or with changes in temperature. Mineral wool is dense, ranging from 2 lb. to 4 lb. per cu. ft. versus 0.4 lb. to 1.4 lb. per cu. ft. for fiberglass.

BLOWN

Mineral wool is available for blown installations either by itself as loose fill (generally for attics), or mixed with a binder and sprayed into framing cavities or onto foam as a fire retardant.

Photos this page: top left and right, Rodney Diaz; bottom, courtesy of Amerrock. Photo facing page: Mark Yanowitz. Drawings: John Hartman.

BOARDS

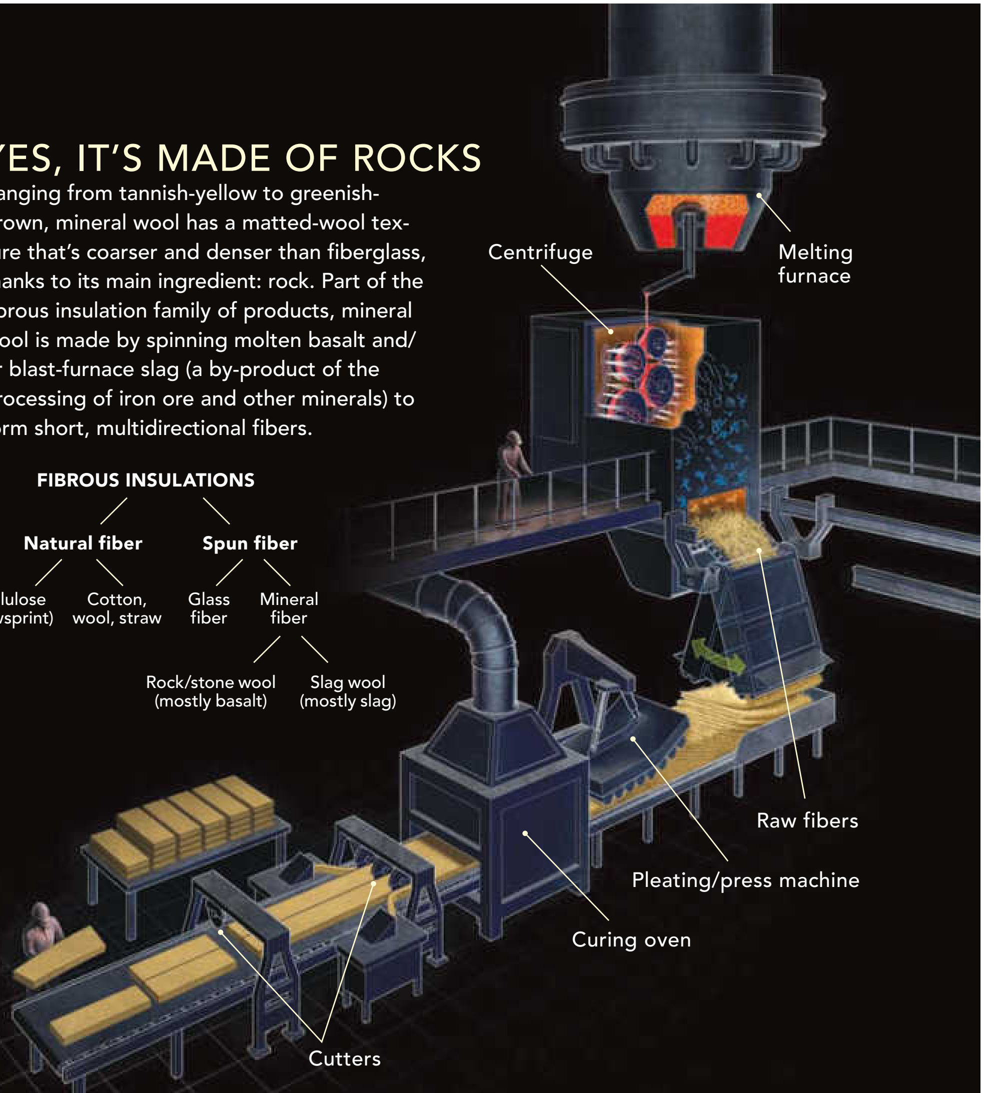
Mineral-wool boards are almost as stiff as rigid foam and are always about 48 in. long, between 16 in. and 96 in. wide, and between 1 in. to 3 in. thick. Denser than mineral-wool batts as well as rigid-foam boards, which have a density of between 0.75 lb. and 3 lb. per cu. ft., these boards range from 4.4 lb. to 8 lb. per cu. ft. (and up to 15 lb. per cu. ft. for commercial grades). They can be used both for interior and exterior applications.

YES, IT'S MADE OF ROCKS

Ranging from tannish-yellow to greenish-brown, mineral wool has a matted-wool texture that's coarser and denser than fiberglass, thanks to its main ingredient: rock. Part of the fibrous insulation family of products, mineral wool is made by spinning molten basalt and/or blast-furnace slag (a by-product of the processing of iron ore and other minerals) to form short, multidirectional fibers.

FIBROUS INSULATIONS

- **Natural fiber**
  - Cellulose (newsprint)
  - Cotton, wool, straw
- **Spun fiber**
  - Glass fiber
  - Mineral fiber
    - Rock/stone wool (mostly basalt)
    - Slag wool (mostly slag)



SUPPLY AND DEMAND Although more available than ever before, mineral wool still competes for shelf space. Batts are typically 60% to 70% more expensive than fiberglass, and boards are at least 80% more expensive than rigid-foam boards.

Johns Manville

Thermal batts (TempControl) and sound-control batts (Sound & Fire Block); no board insulation for the residential market
AVAILABILITY Widely available at Lowe's from the Southeast to the West Coast
COST PER SQ. FT. R-15 batts = 63¢

Owens Corning/Thermafiber

Thermal batts, also good for sound and fire control (UltraBatt); no board insulation for the residential market
AVAILABILITY UltraBatt distributed in the north-central United States through Menards.
COST PER SQ. FT. R-15 batts = 77¢ to 93¢, R-23 batts = $1.08 to $1.16, R-30 batts = $1.53 to $1.58

Roxul

Thermal batts (ComfortBatt) and sound-control batts (Safe'n'Sound) in widths designed for 16-in. and 24-in. framing cavities; board insulation (ComfortBoard IS insulating sheathing) in 1¼-in., 1½-in., 2-in., and 3-in. thicknesses, and in 24-in., 36-in., and 48-in. widths (also available is the 1-in.-thick ComfortBoard FS firestop product, sold in 16-in. and 24-in. widths)
AVAILABILITY Batts commonly available nationwide; board insulation typically special ordered and only in large quantities, but internet retailer Small Planet Workshop stocks smaller quantities
COST PER SQ. FT. R-15 batts = 66¢ to 79¢, R-23 batts = $1.00 to $1.15, sound-control batts = 74¢ (3 in. thick), board insulation = $1.80 (2 in. thick) and $2.79 (3 in. thick)

Amerrock

Loose mineral wool for blown installation (Rockwool Premium Plus) and FireStopTB sprayed thermal barrier; no boards or batts
AVAILABILITY Nationwide through insulation distributors, or direct from the manufacturer
COST PER SQ. FT. R-38 = $2.40 installed ($8.50 for a 30-lb. bag), which is about 30% higher than cellulose but less than half the cost of closed-cell foam

HOW **MINERAL WOOL** STACKS UP

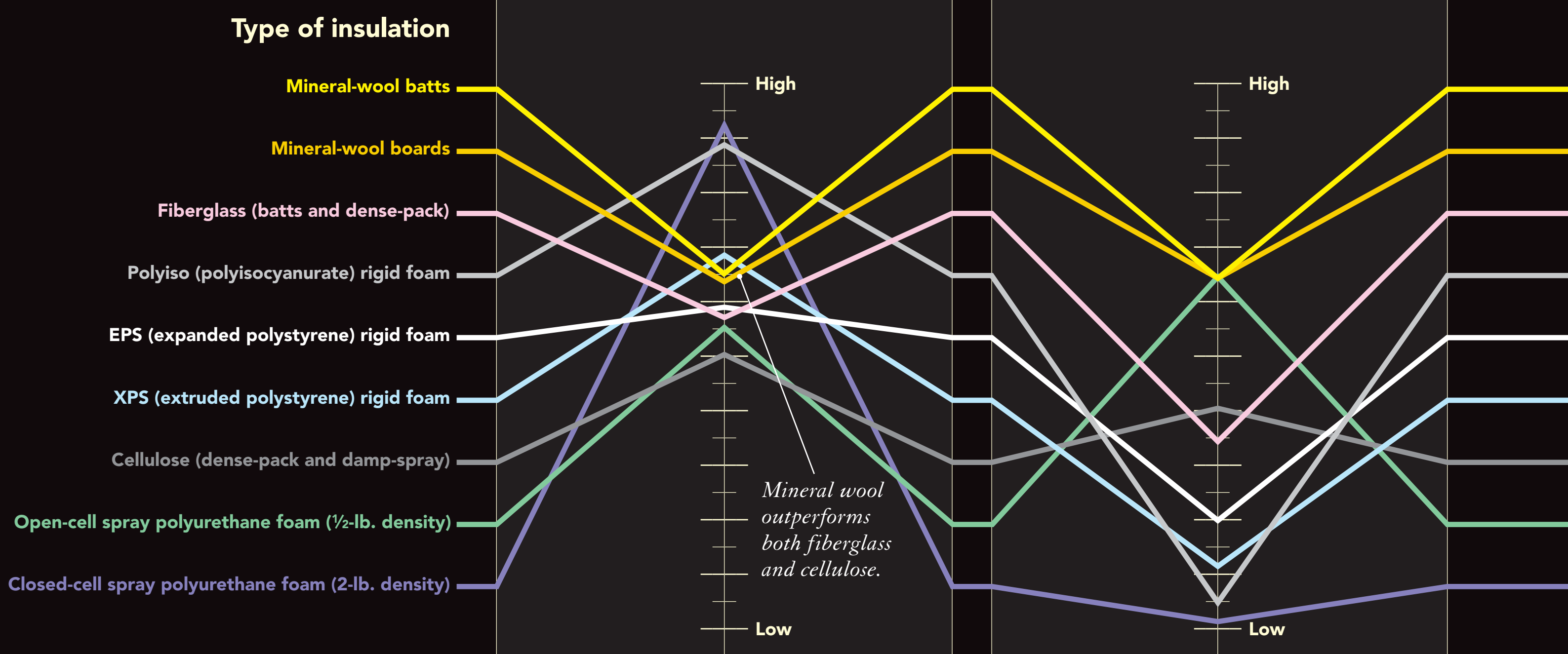
Although it's not easy to do a direct comparison, mineral wool proves to be a strong

Thermal R-value

With R-values from 3.8 to 4.3 per in., mineral wool outperforms the thermal resistance of conventional fiberglass and cellulose, and it lands in the middle of the pack compared to the aged R-values of foam insulation. With a very low coefficient of thermal expansion—just 4% to 8% that of rigid foam—shrinkage in cold weather is also a nonissue.

Water-vapor permeability

In all its forms, mineral wool is very vapor permeable (30 to 40 perms). By code, this requires that vapor retarders be used on interiors in colder climates, but it also means that building assemblies can dry.



MORE POINTS OF COMPARISON

Health concerns

Although mineral wool is chemically inert and contains essentially no VOCs (the products with formaldehyde binders are cured before leaving the factory), respirators and other personal protective equipment are still recommended during installation, as with installations of other types of fibrous insulation. Some people find the fibers itchier than fiberglass, but others consider them less so. According to manufacturers, the fibers settle out of the air quickly due to their relatively heavy weight, so the itch factor may depend on the individual and whether the itch is from contact or airborne fibers. MSDS documents list mineral wool as "not classifiable as carcinogenic to humans." Although products with a mineral-oil additive may create some smoke in the presence of fire, there is no danger of the thick, toxic smoke that accompanies burning foam.

Mold

As do the manufacturers of many building products, mineral-wool producers exercise care with the phrasing "does not support mold growth." In other words, the insulation itself does not provide a food source for mold or other fungal growth, but if temperature and humidity levels are high enough, mold could still appear in framing cavities. In fact, one of mineral wool's other markets is as a growing medium for plants.

TO OTHER TYPES OF INSULATION

contender in many areas.

Airflow resistance

Although dense enough that wind washing (diminished insulating value due to movement of air) is not a big concern for board products or in attics, mineral wool is still air permeable, and even when it's tightly fit, there still may be some gaps in the installation. For this reason, batts in framing cavities should be combined with some form of air barrier.

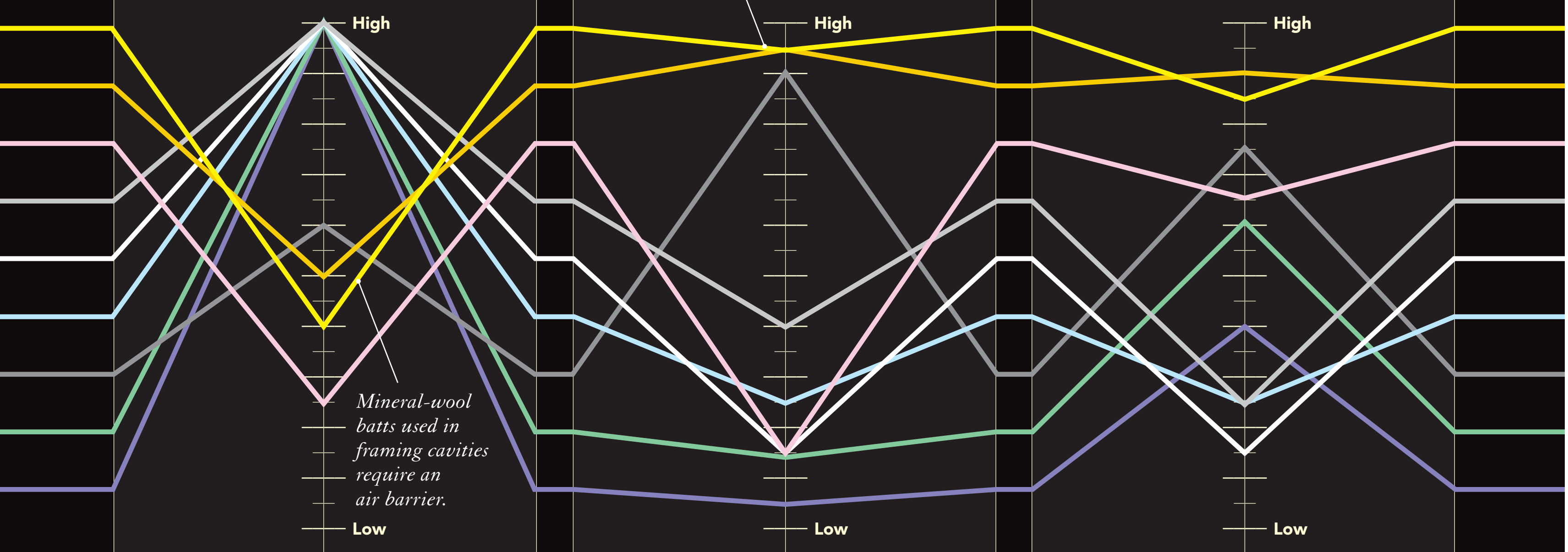
Fire control

Naturally fire resistant and noncombustible without relying on chemical additives, mineral wool has a melting point of over 2000°F and is code approved for use as both draft stopping and as fire blocking. Its flame-spread and smoke-development ratings are low to zero, depending on the specific product.

Sound control

The physical characteristics of mineral wool make it excellent at absorbing sound. "Sound batts," made somewhat denser and in different sizes than batts intended solely for thermal use, can be installed in interior framing cavities to minimize sound transfer. Manufacturers note that mineral wool is only one part of a sound-attenuation strategy, though; for the best performance, refer to assemblies rated for sound-transmission class (STC).

Mineral wool has a melting point nearly twice that of fiberglass.



Environmental impact

Considered green for its typically high recycled content (although some brands use all virgin material), fire resistance, low formaldehyde content, high thermal resistance, and vapor-permeable composition, mineral wool compares favorably to most other insulation products in terms of environmental impact. According to a Building Green report, mineral wool's lifetime global-warming potential is lower than that of most foam products and about the same as fiberglass. The only insulation material that scored significantly better than mineral wool was cellulose.

Liquid water

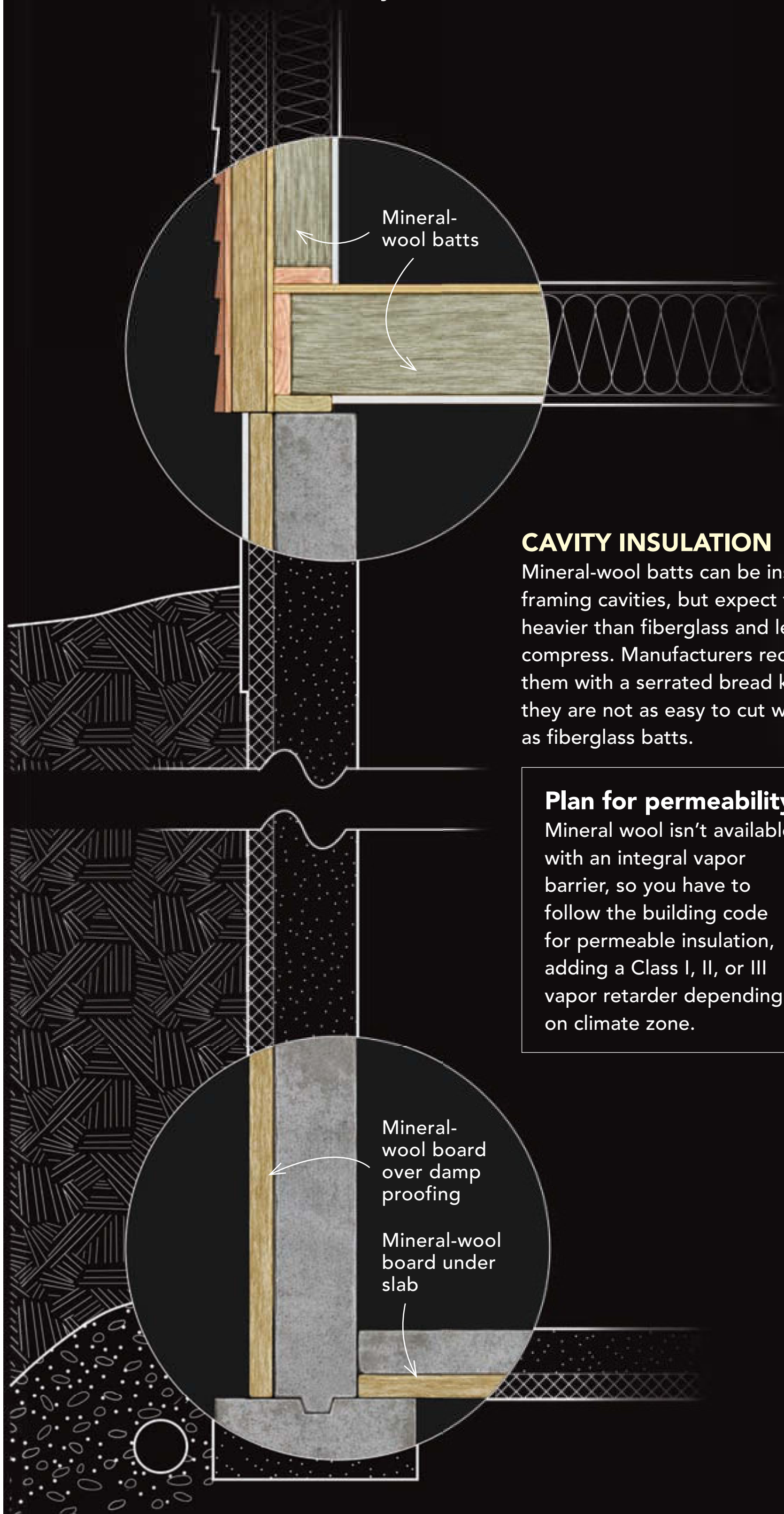
Thanks both to a light-bodied oil added during the manufacturing process and to the nonporous nature of its fibers, mineral-wool insulation is highly resistant to water absorption. Mineral-wool fibers are stocky, allowing liquid water to drain without harm, even in batt products.

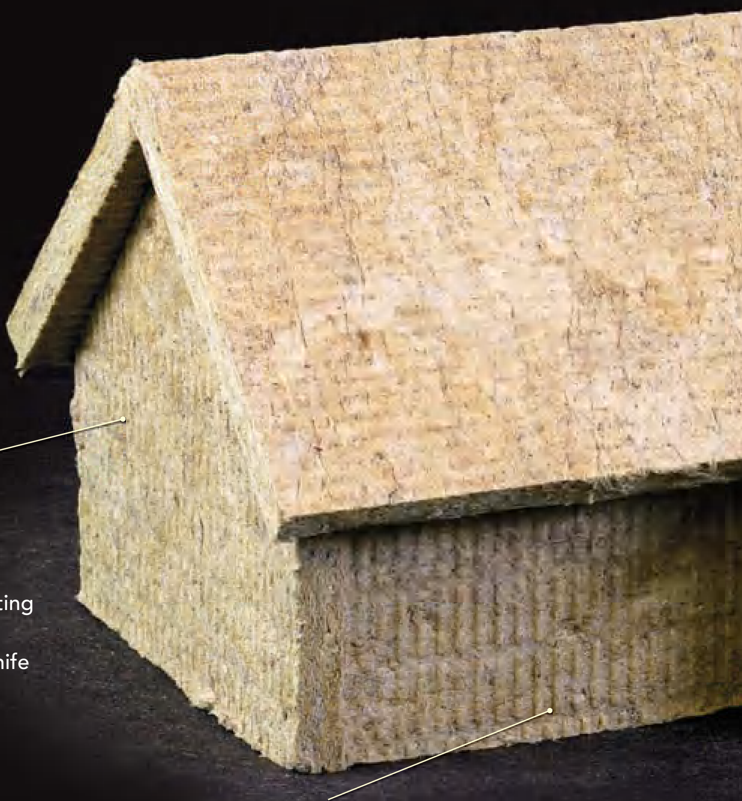
Pests

Other than its density, there is nothing in mineral wool to deter rodents or insects, and birds have been known to nest in exposed exterior mineral wool. As with most types of insulation, care should be taken in other ways to keep pests out.

AT HOME IN MOST APPLICATIONS

Manufacturers and insulation contractors cite sound attenuation and fire safety as the two major reasons for using mineral wool, but the product has plenty of thermal advantages as well. Here’s what you need to know about installing it in various applications.





CAVITY INSULATION

Mineral-wool batts can be installed in framing cavities, but expect them to be heavier than fiberglass and less likely to compress. Manufacturers recommend cutting them with a serrated bread knife because they are not as easy to cut with a utility knife as fiberglass batts.

Plan for permeability

Mineral wool isn’t available with an integral vapor barrier, so you have to follow the building code for permeable insulation, adding a Class I, II, or III vapor retarder depending on climate zone.

BASEMENTS AND FOUNDATIONS

When insulating first-floor joists, or the ceiling of a crawlspace or basement, keep the batts tight to the floor sheathing, and add a vapor retarder. Because of the risks involved, avoid using mineral wool or any permeable insulation on the interior face of a basement wall.

A study by the Danish Technological Institute found that mineral wool installed below grade remained effective and unaltered by compression over 30 to 35 years. Damp proof or waterproof the exterior face of the concrete before installing the mineral wool, backfill with well-draining soil and filter fabric, and extend the insulation to the top of the foundation wall. Cover it with cementboard, stucco, or another durable material.

Roxul’s ComfortBoard IS is approved for use below slabs at non-load-bearing locations, but it is not approved for use under frost-protected shallow foundations.

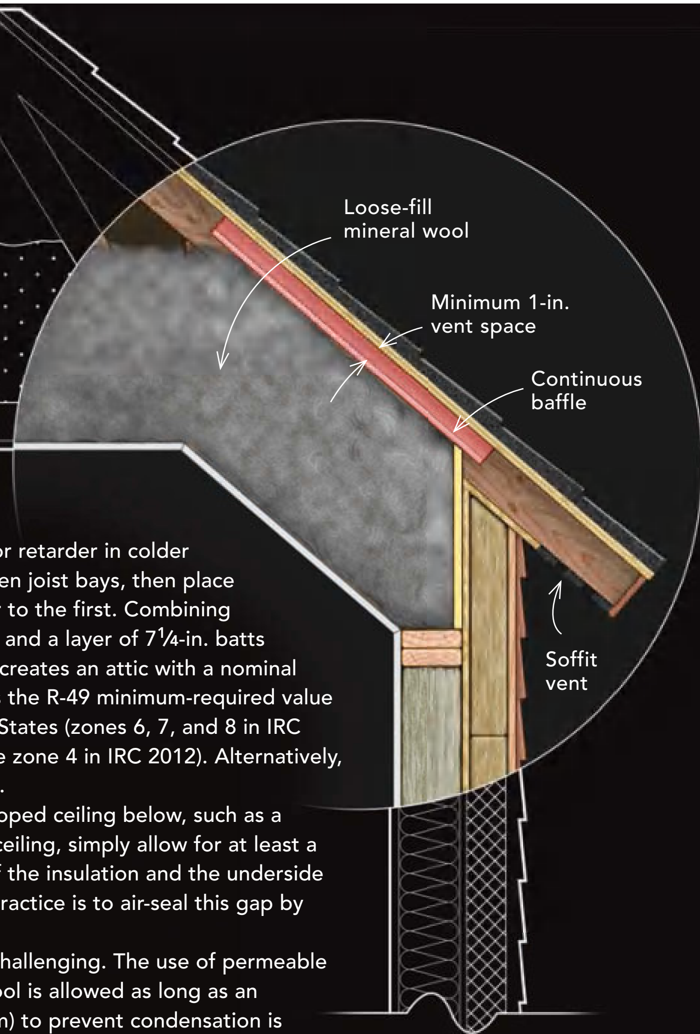
Keep joints tight

Unlike foam (whose joints can be sealed with tape or spray foam) or faced fiberglass batts (which can be stapled into place), mineral wool relies on tight physical contact to avoid thermal “short circuits.”

Photo: Rodney Diaz

Plays well with others

Used regularly in flash-and-batt applications, mineral wool is a cost-effective companion to a thin layer of spray foam applied against the interior side of wall sheathing. This approach is also appealing for its acoustical performance, as closed-cell foam does little for sound control.

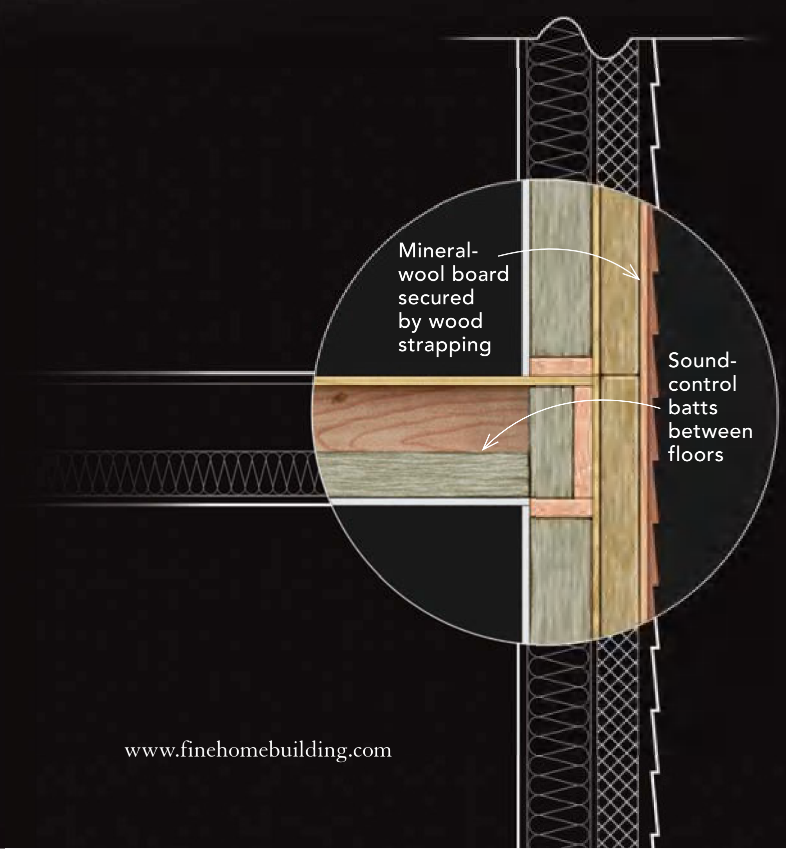


ATTIC AND ROOF

On attic floors (above a vapor retarder in colder climates), install batts between joist bays, then place a second layer perpendicular to the first. Combining a layer of 5½-in. batts (R-23) and a layer of 7¼-in. batts (R-30), with all seams offset, creates an attic with a nominal R-value of 53, which exceeds the R-49 minimum-required value for cold zones in the United States (zones 6, 7, and 8 in IRC 2009, plus zone 5 and marine zone 4 in IRC 2012). Alternatively, use the loose-blown product.

For a vented roof with a sloped ceiling below, such as a typical vaulted or cathedral ceiling, simply allow for at least a 1-in. gap between the top of the insulation and the underside of the roof sheathing. Best practice is to air-seal this gap by using continuous baffles.

Unvented roofs are more challenging. The use of permeable insulation such as mineral wool is allowed as long as an impermeable insulation (foam) to prevent condensation is installed either directly above or directly below the roof sheathing. Generally, a greater proportion of impermeable insulation is required the farther north you are.



EXTERIOR INSULATION

According to Building Science Corporation, the water-resistive barrier (WRB) should go on the face of the sheathing when installing exterior mineral-wool board insulation. You also can use a sheathing with an integral WRB, such as Huber's Zip System product. The WRB or sheathing layer is also a good location for the air barrier in all climates as long as the framing cavities allow drying toward the inside (i.e., no closed-cell foam). It is also a good location for the vapor retarder, when required, as long as the proportion of exterior insulation to interior insulation keeps the vapor retarder above the dew point. Keep in mind that because of its lower R-value per inch, a thicker layer of mineral-wool board insulation is required to reach the same R-value as foam.

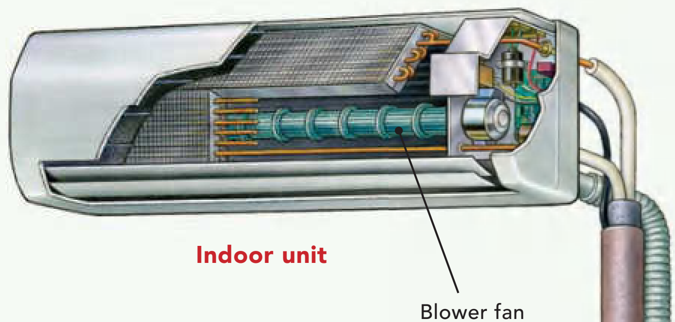
Heavy hanger

Although commonly attached like rigid foam—with screws driven through wood strapping—mineral wool tends to compress slightly, so creating a flat plane for siding takes finesse. HECO screws (smallplanetworkshop.com) designed to attach strapping without overly compressing the insulation is one option; thermally broken fiberglass standoffs to support strapping are another.

Installing a Minisplit

What you need to know about choosing a minisplit heat pump and ensuring that it's set up correctly

BY PATRICK McCOMBE

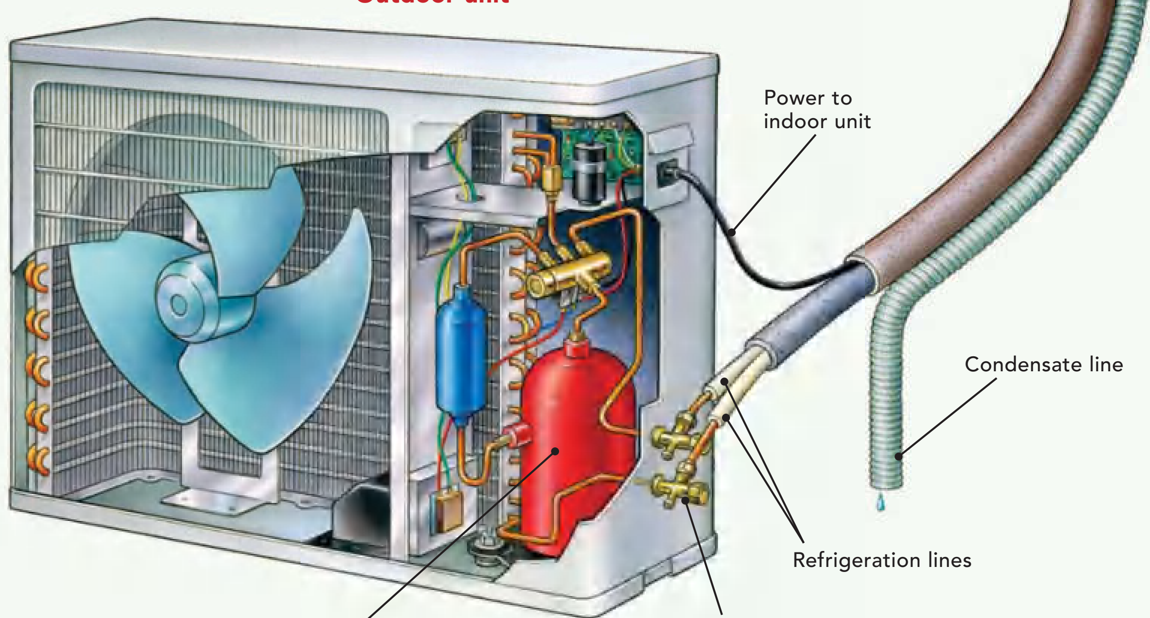


Although they've been around for a couple of decades and are common in Asia and Europe, minisplit heat pumps only recently have started to get traction in the United States. A minisplit heat pump uses a refrigeration cycle to warm or cool the air inside a building. In cooling mode, it extracts heat from within the building and moves it outside. In heating mode, it works in reverse, extracting heat from the outdoor air (even in very low temperatures) and moving it to the building's interior.

There are exceptions, but minisplits generally don't have ductwork. Instead, a minisplit has an air handler and a refrigeration coil in a self-contained wall-mounted or ceiling-mounted unit. Temperature and fan speed generally are controlled with a handheld remote, but they can be operated with a wall-mounted thermostat.

When they were first introduced to this country, minisplits were thought of as an add-on to a central heating and cooling system and a way to condition hard-to-cool spaces. More recently, they have become an efficient way to heat and cool entire houses, often for less installed cost than a central system with ductwork. Here, I'll answer the most common questions about minisplits and will walk you through a typical installation so that you know what to expect when the HVAC tech shows up.

Patrick McCombe is an associate editor. Photos by the author.



A minisplit is a split refrigeration system, with an indoor air handler and an outdoor unit that houses the compressor. These systems are mini because they are much smaller than typical central air conditioners or heat pumps (9000 to 15,000 Btu for a single minisplit vs. 30,000 to 60,000 Btu for a central air conditioner or heat pump).

Drawing: Don Mannes

INSTALLATION STARTS WITH THE INDOOR UNIT

The indoor unit hangs from a metal bracket that's attached to wall framing with screws. The unit's refrigeration and condensate lines run through a 3-in.-dia. hole adjacent to the bracket. The bracket must be hung level for aesthetics and so that the condensate drains properly.

Extras add to the cost. *Beyond what's supplied by the manufacturer, the installer needs enough refrigeration line and 14-ga. four-conductor cable for connecting the indoor units to the outdoor unit. Every indoor unit also needs enough condensate tubing to reach outside or to an interior drain. Every outdoor unit needs a wall bracket or pad for mounting.*

Made for easy mounting. *Using the instructions to determine the right location, the installer drills a 3-in. hole for running the refrigeration lines, electrical cable, and condensate tubing to the outside. The bracket is then leveled and mounted the specified distance from the hole. The bracket should be attached to two studs.*

Connections require access. *The indoor unit's short lengths of refrigeration tubing and condensate line must be extended to reach the outdoor unit. If the unit is on an outside wall, the extended lines are run on the outside of the building. If the unit is on an interior wall, either the lines need to be roughed in before the drywall is hung, or a hole needs to be cut to extend them.*

Q&A

Is a minisplit less expensive than a furnace or a boiler?

Maybe. The smallest 9000-Btu system can be found for under $1000. Installation runs several hundred dollars more. A whole-house turnkey system with normal installation conditions costs anywhere from $2000 to $10,000 and depends on the number of indoor and outdoor units, the complexity of the installation, and local labor rates.

Is installation complicated?

No. Retrofit installations take about a day. The installer drills a 3-in. hole through the wall near the indoor unit for the two refrigeration lines, the condensate line, and the electrical cable. After mounting and connecting the indoor and outdoor units, the installer clears the refrigeration lines of air, tests for leaks, and charges the lines with refrigerant.

Can I install a minisplit myself?

No. At a minimum, clearing the refrigeration lines of air and water vapor requires a vacuum pump ($200) and a refrigeration manifold gauge set ($150). Depending on the distance between the indoor and the outdoor units, you also may need to add refrigerant, which requires a precision scale to measure accurately. Finally, to buy and handle the refrigerant, you need training and EPA certification.

Can a minisplit heat and cool my entire house?

Yes. Multiple minisplits can heat and cool a home of any size in all but the country's very coldest regions. Comfort with a single unit assumes a small, superefficient home with a compact footprint. Some homeowners with a single minisplit have complained that the upstairs sometimes

Continued on p. 77

CABLES AND TUBING ARE ROUTED OUTSIDE

The indoor unit is connected to the outdoor unit with a pair of refrigeration lines and an electrical cable. The lines and the cable can be hidden within walls or inside a plastic covering called line-set ducting. The lines also can be left exposed on the building's exterior.

Line sets should take a direct path. *Pairs of insulated soft copper tubing make up the refrigeration line set. In this installation, the line set, four-conductor cable, and condensate tubing run from the indoor unit toward the outdoors through an attic crawlspace. The bundle of tubes and wire requires a 3-in. hole that will be sealed later with duct-sealing compound for weathertightness.*

Reflare the fittings. *The copper refrigeration lines have flare connections. The line sets come preflared and with their own flare nuts, but manufacturers recommend removing these nuts and reflaring to accommodate the flare nuts that come with the indoor and outdoor units.*

Condensate line runs downhill. *Condensation produced during cooling mode is drained to the outside or to an interior drain through a $5/8$-in. flexible hose. The hose should slope a minimum of $1/4$ in. per ft. for its entire length. When there's no way to drain the water via gravity, a condensate pump within the indoor unit or mounted externally can pump the condensate outside or to a drain.*

Power comes from the outdoor unit. *The indoor unit is powered by the outdoor unit through a 14-ga. four-conductor cable. The stranded cable is as flexible as an extension cord, so it's easy to run it and to make the connections. Some versions have reinforced UV-stabilized jackets, so they can be left exposed without a protective conduit.*

MOUNTING THE OUTDOOR UNIT

The outdoor unit, which houses the compressor and the control circuitry, requires 220v AC power for operation. By code, the power supply must include a "service disconnect" with a 110v receptacle so that HVAC technicians can power their service equipment or turn off the power during repairs.

Secure the outdoor unit. *The outdoor unit either is screwed to a small concrete or plastic slab on the ground, or is attached to wall-mounted brackets. In both cases, the outdoor unit should be installed above the anticipated snow level. If it gets buried in snow, the unit will freeze up and stop operating.*

Plan for noise. *A minisplit's outdoor unit is surprisingly quiet, but it should be located so that it's far from bedroom walls, bedroom windows, and outdoor living spaces. The wall brackets shown have rubber mounts for reducing vibration and noise that can travel through the house's framing.*

Q&A

Continued from p. 75

gets too hot in the summer. For more even temperature distribution, it's best to have one unit upstairs and one unit downstairs. In this scenario, the upstairs minisplit does most of the cooling, and the downstairs unit does most of the heating.

Are minisplits one size fits all?

No. The unit size depends on the size of the space you're planning to heat and cool, the space's insulation and airtightness levels, and your climate. Code requires the HVAC technician to perform a Manual J to account for all of these factors.

Are minisplits reliable?

Yes. Unlike a conventional central heating and cooling system, which is comprised of dozens or even hundreds of parts from multiple manufacturers that are then assembled on-site, a minisplit has matched components that require very little on-site assembly. Also, there's no fine-tuning of the components (a process known as commissioning) as there is with a conventional central air-conditioning or heating system.

Will a minisplit work on the coldest days?

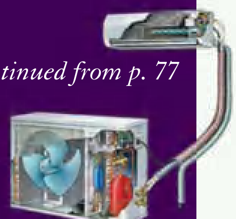
Maybe. Conventional heat pumps typically employ backup electric-resistance heating around 40°F to make up for the lack of available heat in the outdoor air. A cold-climate minisplit model such as the Mitsubishi HyperHeat can deliver 100% of its rated output down to 5°F. At –4°F, the heating capacity drops to 82% of the rated heating capacity. At –13°F, the heating capacity drops to 62%.

Will a minisplit improve the comfort of my home?

Maybe. Minisplits are great for heating and cooling spaces that are

Continued on p. 78

Q&A Continued from p. 77



tough to make comfortable, such as bonus rooms over garages. They offer more-even heating and cooling because of their variable-speed compressors and multispeed blowers. But they're unlikely to solve comfort complaints related to drafts and air leakage, and they won't reliably heat or cool spaces far from where they are located.

Do I have to remove my existing heating system?

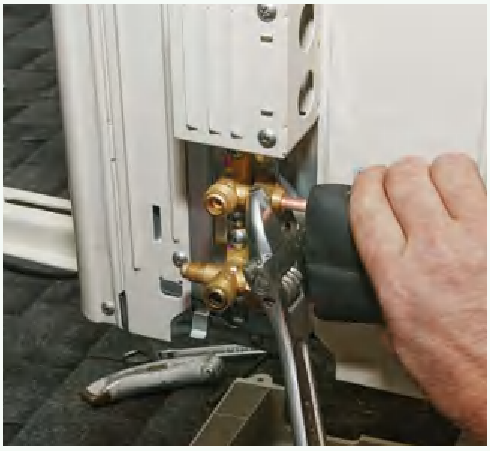
No. In fact, it's generally a good idea to preserve your existing system as a backup for especially hot or cold spells or if something goes wrong with the minisplit. If you are replacing a failed conventional system that has ductwork, it makes sense to remove or seal off any ductwork running through unconditioned attics or crawlspaces. After you've done that, plug any holes that connect conditioned and unconditioned spaces.

Will a minisplit save me money?

Maybe. Minisplits can certainly heat more affordably than electric-resistance heaters. At an outdoor temperature of 30°F, a minisplit provides three times the amount of heat as an electric-resistance system for the same amount of money. Also, if you're cooling your entire house with conventional central air, multiple minisplits likely will be cheaper to run because of their more-efficient variable-speed compressors and more-nuanced zone control. The payback in energy savings for a whole-house system, however, could take so long that it's not worth making the switch until you need a system replaced.

CONNECTING THE OUTDOOR UNIT

The copper refrigeration lines are attached to the service valves on the outdoor unit with flare connections that are the same size as those found on the indoor unit. The 220v AC power and the cable that powers the indoor unit also must be connected.



Outdoor connections look like indoor connections. *The copper refrigeration lines running from the indoor unit are connected to the outdoor unit with flare fittings. As before, the flare nuts installed on the line set are removed and replaced with the nuts provided by the minisplit manufacturer.*

Checking for leaks. *After the copper lines are connected, they're pressurized to about 300 psi with nitrogen to test for leaks. A manifold gauge should show steady pressure. The fittings are then coated with a refrigeration-specific soap solution. Any bubbles around the fitting indicate a leak.*

Power requirements are reasonable. *Powered by a 20A or 30A circuit, depending on its Btu output, the outdoor unit gets its energy from the disconnect switch through conductors run within a flexible, watertight conduit called a whip.*

Evacuating the line set to prevent problems. *Before the service valves are opened and the 410a refrigerant in the outdoor unit is released, the refrigeration lines must be evacuated of air and water vapor with a vacuum pump.*

Are Drainable Housewraps Enough?

They're a good start, but keeping your house dry and free of rot may require more than just drainage

BY JUSTIN FINK

In an ideal world, the exterior cladding on a house would be smooth, continuous, nonabsorbent, and completely waterproof, protecting the moisture-sensitive structure beneath. But we aren't building submarines—we're building houses. Clapboards, sidewall shingles, and other cladding options all are leaky.

But leaky cladding is OK. Building scientist John Straube, who has long studied the effects of moisture in walls, wrote in 2010 that we must "accept that some water will penetrate the outer surface and remove this water by designing an assembly that provides drainage."

Although most housewraps are able to protect sheathing from occasional wind-driven rain, they don't provide a purposeful route for water that gets behind the siding to drain away or dry out. For that, you need a physical gap between the back of the cladding and the sheathing it's attached to. That's where a new breed of drainable housewraps comes into play.

Essentially, housewraps that have been wrinkled, dressed with bumps, or otherwise designed to maintain a gap provide a small space for water to drain away before it has a chance to cause problems

Photos this page: courtesy of Benjamin Obdyke

ARE YOU SURE YOU KNOW WHAT A RAIN SCREEN IS?

In the building industry, the loose usage of terminology can lead to confusion. For years, people have been using the term *rain screen* to describe a variety of different wall assemblies.

By definition, a rain screen is just one component of what's known as a drained wall system. There are several variations of this system, but it usually includes four components.

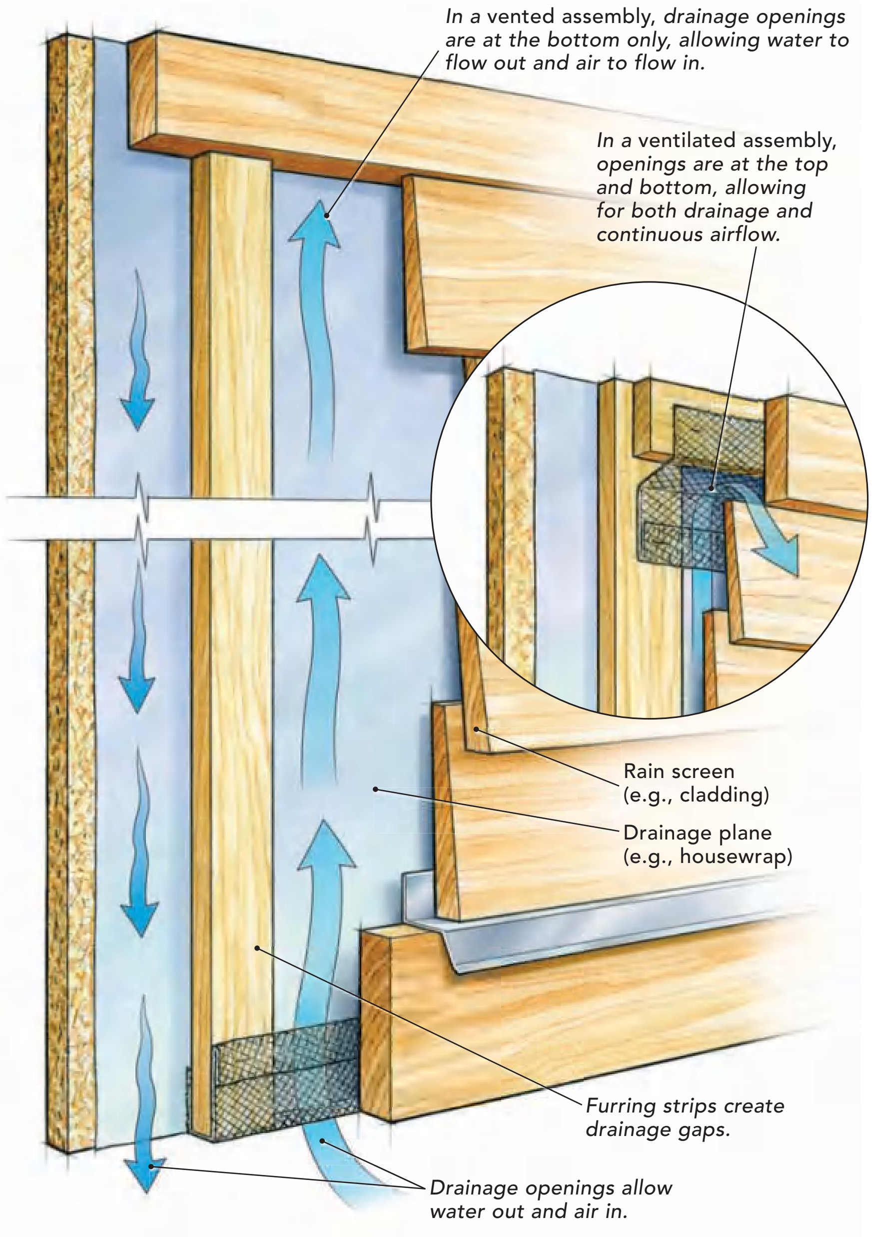
1. A rain screen (i.e., the clapboards, brick, or other cladding) acts as the first layer of deflection for sun, water, and dirt.

2. A drainage plane is the waterproofing layer in the assembly and is protected by the rain screen. This plane is typically in the form of housewrap or felt paper, but it also can be taped foam sheathing or water-resistant sheathing such as Zip System, among other things.

3. A drainage gap is a space between the back of the rain screen and the drainage plane.

4. Drainage openings at the bottom of the wall cavity provide an outlet for any liquid water that is driven into the wall or that accumulates between the back of the rain screen and the face of the drainage plane.

The catch is that a wall with these four components is technically a vented assembly, because the drainage openings allow water to flow out and air to flow in. But in order to be a ventilated assembly (what most of us are likely thinking of when we say a house has a rain screen), it must also include openings at the top of the drainage gap. Working in conjunction with the drainage openings at the bottom of the assembly, the wall now has continuous airflow.



such as peeling paint or rotten sheathing. Unlike when incorporating furring strips or another form of vented drainage, these drainable wraps require none of the additional detailing or rethinking of transitions between windows, trim, and siding, which means they are more likely to get used by builders who aren't willing to change their building details. But the real question is whether a drainable wrap is just a premium version of standard smooth housewrap, or whether it is a comparable substitute for a true ventilated rain-screen system.

Lessons learned from stucco

Drainable housewraps may seem like a new idea, but they actually were borne from the hard-earned lessons of past failures. The problems builders have encountered with stucco are an excellent example.

Stucco is a so-called reservoir cladding, which means that it can absorb and hold water. Warmth from the sun pushes moisture from the surface of the stucco farther into the wall, where it can sit against the sheathing and lead to rot. Decades ago, builders installed a single layer of asphalt-impregnated building paper over the wall sheathing to protect it against this moisture. Scientists realized later that the reason why this single layer worked so well is that as the stucco dried, it debonded from the building paper and left small gaps, which allowed water to drain away. Over time, however, the manufacturing methods for building paper changed, and a single layer of the newer paper maintained its bond with the stucco rather than debonding like the old stuff; as a result, the drainage space wasn't created. Around the same time, builders started switching from plywood sheathing to OSB sheathing, which is more moisture sensitive (see "The Mold Explosion: Why Now?" *FHB* #184). You can guess how the story ended: Lots of builders were forced to deal with catastrophic cases of rotten sheathing.

Photos facing page: Dan Thornton. Drawings: Don Mannes.

To solve the problem, builders started applying two layers of building paper instead of just one. The outermost layer bonded with the stucco and was meant to be sacrificial, while the inner layer was undisturbed and able to protect the sheathing. Best of all, a small gap between the two layers provided drainage.

Nowadays, a double layer of building paper (or a membrane with performance equivalent to two layers of building paper) is required by building codes for stucco and manufactured-stone installations.

A small gap is enough

The benefits of drainage extend beyond masonry. In a 2004 paper, Straube declared drainage behind the siding of a house to be "the first and fastest means of removing water that penetrates [cladding]."

Straube's research—which has since been supported by others and carried like a trophy by manufacturers of drainable housewraps—proves that even an extremely small gap (1 mm, or about 1/32 in.) drains water from behind cladding faster than rainwater can penetrate, even under extreme weather conditions. (Not coincidentally, all of the drainable housewraps I looked at for this article provide a gap of between 1 mm and 1.5 mm.)

Benjamin Obdyke's website states that the company's HydroGap drainable wrap "drains moisture from wall assemblies at least two times faster than the leading drainable housewrap and removes 100 times more bulk water than standard housewrap." Tamlyn claims on its website that TamlynWrap produces the "drying capability of a 3/8-in. rainscreen without the cost by creating a needed cavity." But the picture being painted by drainable-housewrap marketing—a stream of water running harmlessly behind the cladding thanks to the gap provided by the membrane—isn't the best representation of the problems most builders are faced with.

That's not to say that the drainable housewraps won't provide this level of drainage—just that this much water getting behind clad-

1 MM GOES A LONG WAY TOWARD DRAINAGE

Although water-resistive barriers (WRBs) are able to protect sheathing from incidental water intrusion, they need extra help at draining built-up water. To eliminate this water, a gap is needed between the back of the cladding and the face of the WRB. Research done by building scientists shows that a housewrap with a gap of 1 mm, or even less, allows for a surprising amount of drainage. This drainage space can be created in a number of different ways.

Bumpy

Benjamin Obdyke's HydroGap (shown) and Tamlyn's TamlynWrap are two examples of how a drainage space can be achieved by simply adding dabs of soft rubber or plastic to the face of a woven housewrap.

Crinkled

Tyvek's StuccoWrap and DrainWrap (shown) are among the first products in this category of housewrap. Resembling housewrap that's been scrunched into an accordion pattern, they have minimal drainage channels that must run vertically to be effective.

Stamped

Similar to the surface of a basketball, the texture of wraps such as Barricade Building Products' WeatherTrek (shown) is nondirectional, as on bumpy housewraps, to ensure drainage regardless of the wrap's orientation in relation to the siding.

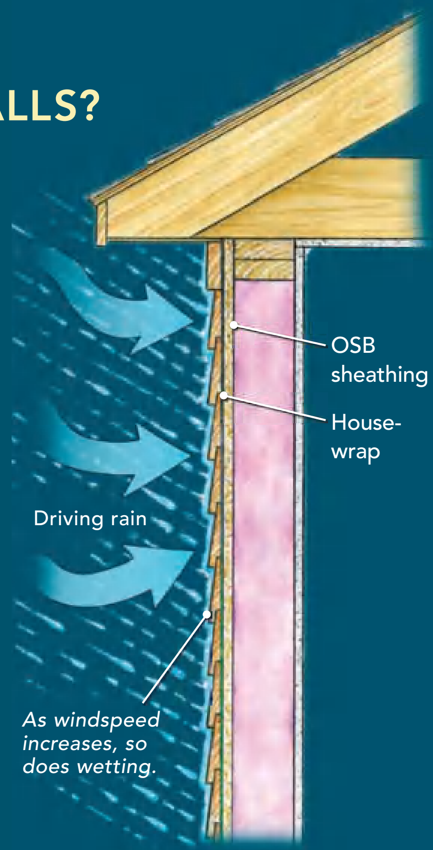
Channeled

Although the space created by the exaggerated weave of Kingspan's GreenGuard Raindrop 3D (shown) and similar wraps isn't especially deep, it's good enough. As with crinkled wraps, the channels must run vertically to be effective.

WHY ALL THE WET WALLS?

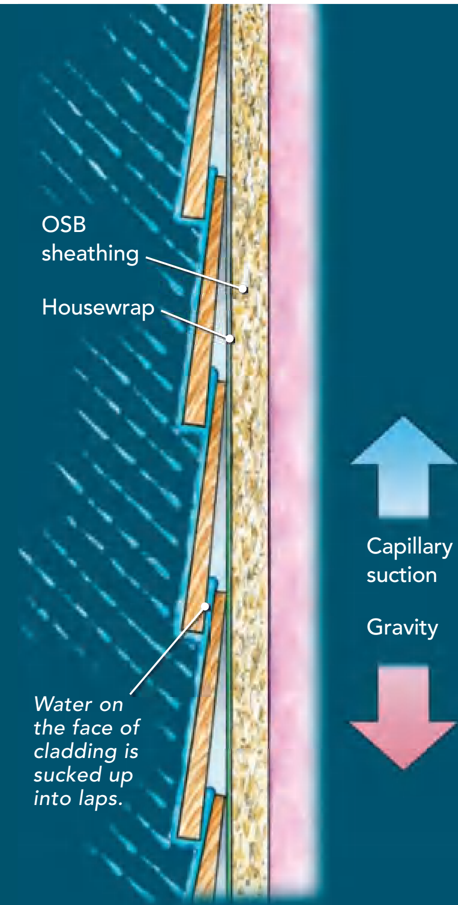
Builders have been dealing with water for as long as they've been building walls. So why are we talking much more these days about the need for drainage and airflow behind siding? Some of the biggest changes affecting wall durability in recent years have been the introduction of housewrap, the shift from plywood sheathing to OSB, and the increase in levels of insulation, much of it highly vapor retardant. But these changes in building materials aren't the reason for this new focus on drainage and airflow; they're just more-sensitive indicators of the same moisture problems we've been seeing (and getting away with) for years.

Moisture can affect walls through precipitation, capillarity, diffusion/air movement, stored moisture, and groundwater.



Precipitation

Although it is possible for water to be sucked behind the cladding due to wind-related pressure differences, this is rarely the smoking gun when it comes to leakage. The chances of leakage do increase when it's windy, particularly at butt joints and penetrations, but that's because the walls are faced with driving rain (the minimum threshold depends on the overhang and topography), and the amount of water on the wall increases in proportion to the wind speed.



Capillarity

Although capillary suction is more commonly associated with water moving through porous materials—a concrete wall, for instance—it can also be a problem with nonporous materials. When two pieces of siding are lapped tightly, the narrow gap between them can itself become a capillary pore, defying gravity by sucking moisture that has clung to the face of the siding upward and suspending it in the lap joints.

ding isn't common. A more likely problem is water penetrating a wall in less obvious ways that are just as damaging and that may not be solved with drainage alone (see "Why all the wet walls?" above).

Big enough for drainage, but is drainage enough?

Although a small gap can make a big difference in allowing liquid water to pass, the increased levels of wall insulation and the moisture-sensitive building components used in today's houses call for more purposeful airflow than can be provided by a drainable wrap. Liquid water may be able to drain, but liquid water isn't the only worry.

According to Straube's 2004 paper, "A significant amount of water deposited by condensation or rain penetration will remain in an enclosure, absorbed by the materials and adhered to the surfaces." It's this absorbed moisture that's most problematic, because it will not easily dry without the help of air movement, which is not a benefit of a drainable housewrap. So if a 1.5-mm gap provided by a drainable housewrap isn't enough, what is?

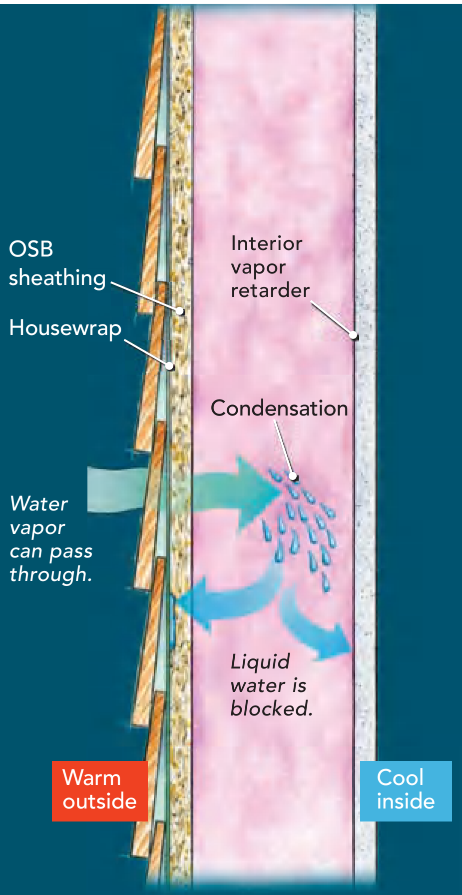
Engineer Joe Lstiburek, principal at Building Science Corporation, wrote in a 2010 article that a ⅜-in. ventilation gap is "a pretty safe dimension with stucco, manufactured stone veneers, wood claddings or other claddings like fiber-cement that lie flat against the housewrap and OSB." (Vinyl and aluminum siding have plenty of air gaps behind them and so don't require any additional airspace.)

Lstiburek called this ⅜-in. gap "very, very conservative" and said that it can be much smaller, depending on the severity of the climate and other variables that scientists haven't accurately measured yet. Lstiburek recommends playing it safe: "With a ⅜-inch gap I have never, ever, anywhere known of anyone to have a problem."

This approach is helpful in every climate, but it's particularly important in rainy climates; in fact, a ⅜-in. gap is a building-code requirement in coastal British Columbia and Oregon.

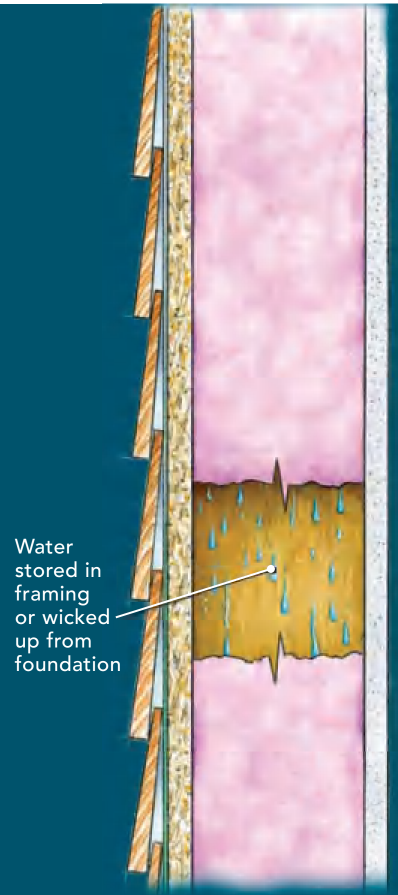
One situation where drainable housewraps are finding their niche is in wall assemblies that include rigid-foam insulation installed on the outside face of OSB sheathing and either vapor-impermeable insula-

Photo: GreenBuildingAdvisor.com



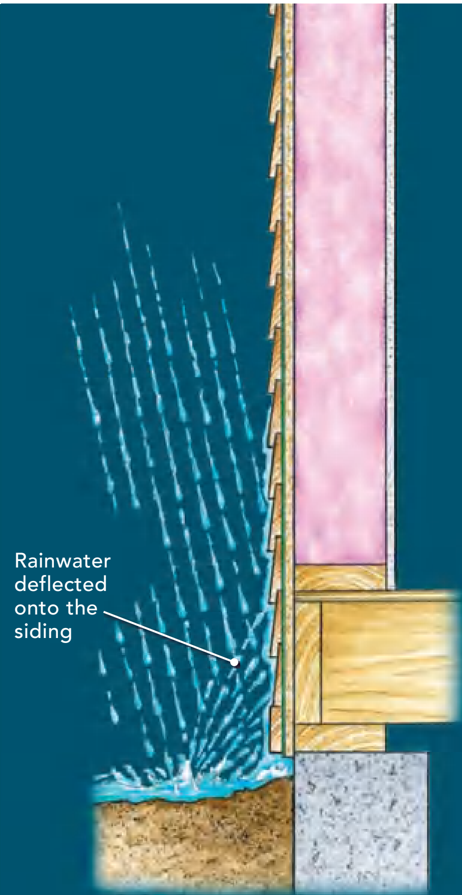
Diffusion/air movement

Housewrap is designed to block liquid water while still allowing the passage of water vapor. But if that water vapor condenses in the wall cavity, it will be unable to pass through the housewrap to dry to the outside, and drying toward the interior is often limited by an interior vapor retarder (e.g., poly sheeting behind the drywall) or high levels of insulation that limit the amount of available heat energy.



Stored moisture

Whether it comes directly from the building materials we use—green framing lumber and concrete that isn't fully cured are two common examples—or from building components being exposed to the elements during construction, stored moisture can take a year or more to dry fully.



Groundwater

The mechanisms at work here aren't wholly different from those of driving rain: gravity and capillarity. In this case, however, gravity takes the form of rain splashing off the ground and onto the siding, and capillarity may come from high concentrations of moisture at ground level (for example, if there are lush garden beds at the base of the wall).

tion or a vapor barrier that prevents drying to the inside, all of which are being used more frequently these days. Lstiburek says that it's possible in these cases to get a sufficient amount of outward drying by providing a small gap between the OSB sheathing and the rigid foam so that water can diffuse. A drainable housewrap not only is helpful in this regard, but it's actually the best solution. A gap larger than 1 mm or so means a reduction in the insulating effectiveness of the exterior rigid foam. According to Lstiburek, with drainable housewrap you lose next to nothing in terms of thermal performance compared to the increased durability and diminished risk of the wall assembly.

A judgment call

It seems that the proper role of drainable housewraps is still somewhat unclear. On the one hand, they provide a space behind siding for drainage, which is one of the best safety mechanisms that can be incorporated into a house. And when it comes to making sure that exterior foam works well with OSB sheathing, they are a true silver bullet, balancing effective moisture redistribution with a very small reduction in thermal performance.

The research findings are pretty well understood and agreed upon when it comes to airflow: A physical gap behind siding is a good thing (although there is a sliding scale), and planned ventilation is even better. In his 2010 article, Lstiburek wrote that providing ventilation is "simple, elegant, and unbelievably effective in helping out drying."

On the other hand, drainable housewraps have limitations compared to an assembly with a more substantial gap. A drainable housewrap will not provide purposeful airflow—certainly not enough to compete with the performance of a ventilated rain-screen wall.

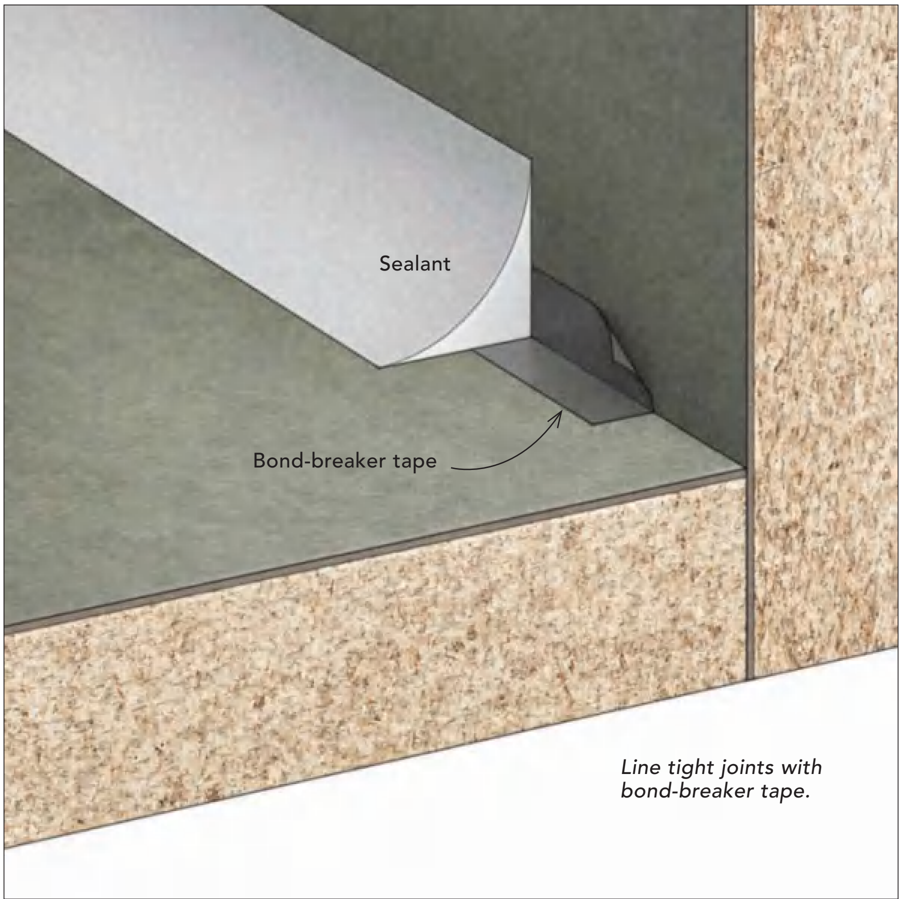
It may be helpful to think of drainable housewraps as falling somewhere in the "better" zone, trailed by a "good" traditional housewrap installation, but not as beneficial as the "best" option: a true ventilated rain-screen assembly. □

Justin Fink is Project House editor.

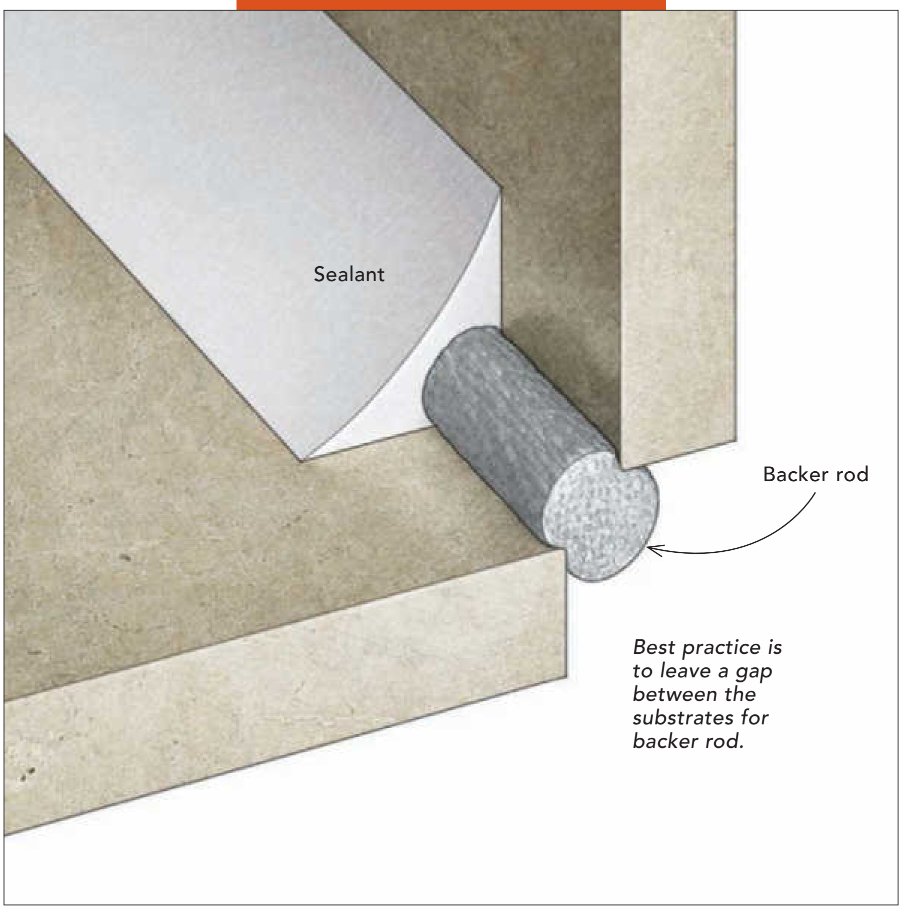
Caulk This Way

Joint design and prep may matter even more than choosing the right product

BY ANDY ENGEL



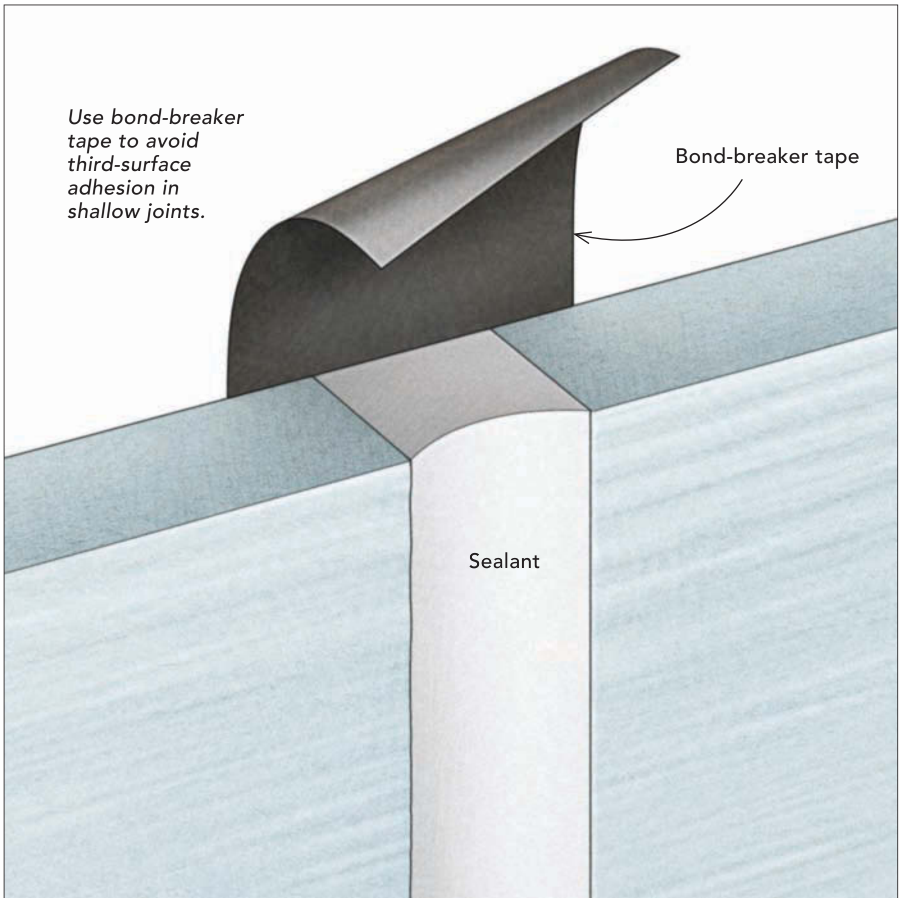
CORNER JOINTS



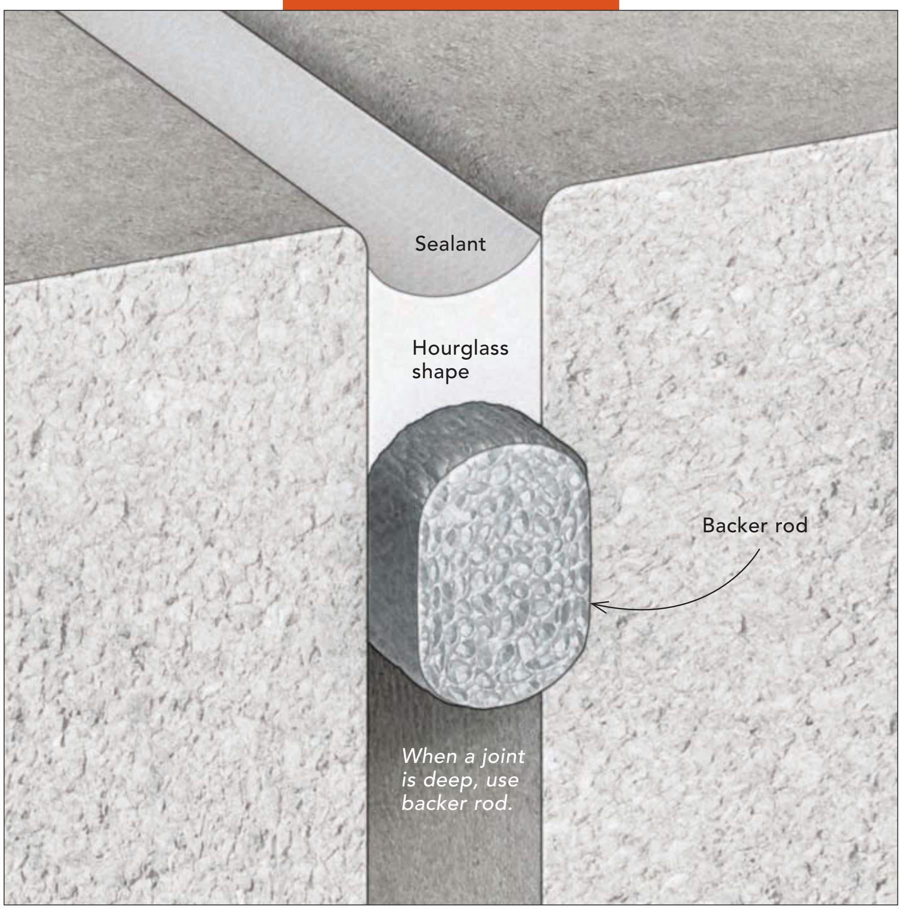
After researching and writing this article, I had an epiphany: In 35 years of doing and writing about residential construction, I have never seen a caulk joint executed properly. Most residential caulk joints I've seen have failed or are likely to. Builders, including myself, barely know which caulk or sealant to use where, and hardly anyone in residential construction knows how to execute a proper joint by considering crack width and depth and the use of backer rod or bond-breaker tape. There is a lot to know.

The first thing to know is that building components move. Builders don't like to acknowledge this. This may be because it feels like a reflection on their work, or because it introduces complexities in material choices and procedures they'd rather avoid, or just because it never occurred to them. Movement happens mostly because of changes in temperature and humidity. We see the results in gaps between materials. In some instances, such as with interior trim, this is only an aesthetic issue. But in other cases—the corners of a shower, the gaps around a window, expansion joints in concrete—such spaces can lead to

Drawings: Christopher Mills



FLAT JOINTS



DESIGNING JOINTS

According to Sika, a major sealant manufacturer, proper joint design and preparation eliminates 95% of callbacks for sealant failure. ASTM C920 covers joint design, including the required sealant depth where it meets the substrate, which depends on both the width of the joint and whether the surface is porous or not. Porous surfaces are found on materials such as concrete, masonry, fiber-cement siding, and raw wood. Examples of nonporous surfaces include aluminum, steel, glass, tile, painted wood, and plastics. There are three golden rules of sealant joints: They must be at least ¼ in. wide, surfaces must be clean, and the sealant must adhere only to two surfaces. Bond-breaker tape and backer rod are used to prevent the sealant from adhering to the back of the joint.

WIDTH-TO-DEPTH RATIOS

Joint width	Sealant depth
Porous substrates	
¼ in. to ½ in.	Equal to the joint width
½ in. to 1 in.	Half the joint width
Nonporous substrates	
¼ in. to ½ in.	¼ in.
½ in. to 1 in.	Half the joint width, maximum ⅜ in.

Control your sealant

While backer rod is readily available from home centers and hardware stores, bond-breaker tape is easier to find online.

crlaurence.com
nationalsealantproducts.com
sealantengineering.com

SEALANT PROPERTIES

No sealant does everything well. The trick is choosing the sealant that meets the requirements of the job and works for the conditions at hand. The properties discussed here are general, and some specific products within the category may perform better or worse than what's typical.

ACRYLIC/LATEX

Often the least expensive choice, these water-based caulks cure by evaporation. Consequently, they can shrink by a quarter to a third of their volume before they're fully cured. They hold paint well and usually can be painted within four hours. Most aren't as flexible as many other sealants, but they're a good choice for filling small gaps between interior-trim pieces.

BUTYL/RUBBER

The original modern sealant, butyl dates from the 1920s. It cures through the evaporation of organic solvents, shrinking a quarter to a third in the process. Butyl is sticky and can be harder to tool than other sealants, but it can be used in freezing weather. Best used outdoors because of its odor before curing, butyl is less common in residential construction than other sealants.

POLYETHER/SILICONE

So-called STPE (silyl-terminated polyether) sealants are similar to and sometimes superior to polyurethanes. Relatively new to the U.S. market, STPEs have been used in Japan for decades. Based on polypropylene glycol, they cure by reacting with water. The cure rate is much faster than that of polyurethanes, and STPEs can be painted sooner. They can be used on damp surfaces and in below-freezing temperatures, making them a good choice for outdoor use.

TYPE OF SEALANT	Acrylic/latex	Butyl/rubber	Hybrid polyether/silicone (STPE)
WORKING TEMPERATURE	40°F to 120°F	20°F to 100°F	0°F to 120°F
CURING METHOD	Water evaporation	Solvent evaporation	Reaction with water
TIME BEFORE PAINTING	2 to 4 hours	7 to 14 days	1 to 2 hours
MOVEMENT RANGE	12.5% to 25%	12.5% to 25%	25% to 50% typical, up to +100%/–50%
BEST FOR	Aluminum, concrete, fiber cement, masonry, vinyl, wood	Aluminum, concrete, fiber cement, masonry, steel, vinyl, wood	Aluminum, concrete, fiber cement, many plastics, masonry, steel, vinyl, wood
AVOID	Steel	N/A	N/A

serious effects by allowing unwanted air or water to enter. The solution isn't necessarily to make tighter joints, but rather to design the joints for the realities of the environment and the material, and then to install a good sealant properly.

I'm not arguing against good workmanship. The best caulk ever made still can't make a badly executed interior-trim joint look good, for example. But good workmanship sometimes means leaving a gap that's sized to allow a proper caulk joint. Many materials move so much with changes in temperature and humidity that no joint will stay tight, and so a flexible sealant is exactly the ticket. In fact, the manufacturers of building materials such as PVC trim, fiber-cement or wood-composite sidings, and vinyl windows actually specify gaps at joints to allow for movement and caulking. Good caulking is good workmanship, but maybe because caulking a joint feels like punting on quality—something done when a person lacks the skill or care to fit materials tightly—it gets short shrift. It's often not even clear whose job it is. The painter's? The carpenter's?

In commercial and institutional construction, caulk joints are expected to last for 10 to 20 years. In fact, the materials aren't even called caulks, but rather sealants. Joint design and sealant choice are handled by the designer (based on ASTM C1193), and the work is done by a specialty contractor. Mock-ups of building assemblies are made on-site so that the specified sealants can be tested for effectiveness with samples of the materials that will be used.

POLYURETHANE
Although urethane cures by reacting with moisture, it shouldn't be applied to wet surfaces or when rain is in the immediate forecast. An excess amount of water can cause a reaction that releases an undesirable amount of CO_2, which can cause the sealant to froth and compromise its ultimate strength. Although hard to tool, polyurethane sealants are paintable, long lasting, and abrasion resistant.

POLYURETHANE/SILICONE
These SPUR (silyl-terminated polyurethane) hybrids have characteristics similar to STPEs. Like STPEs, SPURs rely on groups of a long-chain polymer (in this case, polyurethane) for the backbone of the sealant, and groups of a second polymer (silyl or silane) for the ends. The long-chain polymer provides both elasticity and cohesive strength, while the silyl endcaps provide adhesion.

SILICONE
Early versions of silicone caulk had a so-called acid cure and released a vinegar smell. Modern silicone cures by reacting with moisture and gives off very little odor. Silicone bonds at a molecular level with glass, making it a good choice for frameless shower doors and tile. It doesn't take paint, and not even silicone sticks to where silicone has been used before, so recaulking usually requires mechanically removing some of the previous substrate.

There's usually no downside to using a more elastic caulk except that it will cost a little more. Given the small amount of caulks and sealants most projects require, spending a few bucks more on higher-quality products makes good sense.

Polyurethane	Hybrid polyurethane/silicone (SPUR)	Silicone
32°F to 100°F	41°F to 104°F	20°F to 120°F
Reaction with water	Reaction with water	Reaction with water
Up to 7 days	1 to 2 hours	Never
25% to 50% typical, up to +100%/–50%	25% to 50% typical, up to +100%/–50%	25% to 50% typical, up to +100%/–50%
Concrete, masonry, metal, stone, vinyl, wood	Aluminum, concrete, fiber cement, many plastics, masonry, steel, vinyl, wood	Aluminum, ceramic, enamel, glass, nonporous surfaces, plastics
N/A	N/A	Concrete and masonry, steel

Meanwhile, many of us in residential construction don't even know which of dozens of products to use. The marketing doesn't help; the caulk and sealant aisle is as confusing as a Marrakesh bazaar. Knowledge is the only defense. Caulks and sealants fall into just a handful of categories, and all of them are gauged by ASTM C920.

Caulks and sealants are meant to keep out air and water over the long term. To do these things, a product must balance elasticity, strength (cohesion), and adhesion—that is, it must stretch in response to material shrinkage without tearing or detaching from its substrate. It must compress when the material around it expands, and return to its original shape when the material contracts. Other important characteristics to consider when choosing a product include UV resistance, durability, paintability, and workability. Also, chemicals from a caulk or sealant might stain some surfaces, such as marble.

Understanding performance criteria

ASTM C920 provides a uniform platform for comparing sealants and is often specified on construction documents for commercial buildings. Some products provide C920 data on the tube, while for others, you have to go to the manufacturer's website. C920 incorporates 10 tests and multiple classifications, but the most important consideration is elasticity. Class 12.5 sealants can stretch and compress 12.5%, whereas Class 50 sealants can stretch and compress 50%. There are even Class 100/50 sealants that stretch 100% and compress 50%. This,

Polyurethane safety

Although health problems are more common among spray-foam installers and other workers with high exposures, anyone using a urethane-based product may be at risk. Isocyanates, the building blocks of all urethanes, are the reason. Isocyanates are chemicals that polymerize by binding with OH molecule groups such as are found in water and many organic solvents. Depending on other components, this polymerization forms a variety of useful end products such as paints, wood finishes, glues, insulating foams, and sealants.

According to Christopher Weis of the National Institute of Environmental Health Sciences, "Contact with uncured isocyanates by breathing or through the skin can sensitize workers or family members. Once someone is sensitized, future exposures can cause severe asthma and skin problems."

Asthma isn't just an inconvenience. People have died from isocyanate-induced asthma attacks.

But the news isn't all bad. The California Department of Public Health says, "Fully-cured polyurethanes are non-toxic, unless they are heated. Polyurethane materials give off isocyanates and other toxic substances when they are burned or abraded."

Be cautious with any polyurethane product. While activities such as spray-foam application call for a Tyvek suit, rubber gloves, and a full-face supplied-air respirator, NIOSH standards allow a regular organic-vapor cartridge-type respirator to be used for operations of a short duration. Good ventilation is also recommended, as is avoiding skin contact by wearing nitrile or neoprene gloves.

Stay safe. *Use a respirator and plastic gloves to minimize isocyanate exposure.*

by the way, is a loose way to distinguish between the terms *caulk* and *sealant*. Your local hardware store or home center sells products labeled both ways, but caulks are less flexible than sealants and may have an elasticity factor of less than the 12.5% minimum required to meet C920.

For most exterior uses, Class 25 sealants are sufficient, while for interior use, Class 12.5 might do. Not all caulks comply with C920, but one that doesn't might still perform just fine in filling trim joints so that paint will look good. With interior trim, the most important attributes are fast drying times, ease of application, and paintability. Still, there's usually no downside to using a more elastic caulk except that it costs a little more. But given the small amount of caulks and sealants most projects require, spending a few bucks more on higher-quality products makes good sense.

Some caulks or sealants claim to "meet the performance standards of ASTM C920." That's not the same as complying with ASTM C920, but it may not mean that the caulk is inferior. Often, such caulks are solvent based and shrink more during their cure than the standard allows. It's more important to know the elasticity.

One type of sealant not intended to keep out air and water or to make trim joints look good is acoustical sealant. Its purpose is to keep out sound, although it's often used in energy-efficiency applications such as sealing wall plates to subfloors and plastic vapor barriers to crawlspace foundations. Acoustical sealant never hardens, so it accommodates movement well. It remains sticky and is only used where it's unlikely to be encountered once construction is complete.

Joint size and backer rod

For a sealant to stretch and rebound and to remain adhered to the substrate, there must be enough of it in place. In general, sealants require a gap of at least ¼ in. In fact, ASTM C1193, the standard that governs sealant-joint design, states, "Under no circumstances should a liquid applied sealant [a technical term that includes caulks in a tube] be applied in a joint opening that is less than 6mm (0.25 in.) wide." The standard is concerned with joints that must be weathertight, so this doesn't apply to caulked joints along interior trim, for example. The same standard also provides depth-to-width ratios for sealant application, which are crucial to a durable joint.

Sealants are also meant to adhere to two substrates, stretching and compressing as they move. If you introduce a third surface, such as the material underlying the two substrates, adhesion to that third surface can interfere with the sealant's ability to stretch, and it may crack or detach from the surrounding materials.

Clearly, it's important to manage the depth of the sealant application. That's where backer rod and bond-breaker tape come in. Backer rod is made from open-cell or closed-cell foam and is available in diameters from ¼ in. to 6 in. Curiously, it's often stocked alongside weatherstripping products rather than caulks. Backer rod should be sized so that it's 30% to 50% wider than the joint. It pressure-fits into the joint to create a space based on what's required to achieve the correct sealant depth. It's also available in triangular shapes for corner joints where there is no space between the two substrates. Backer rod is very flexible, and sealants don't tend to stick to it, so it doesn't create third-surface adhesion problems. With proper tooling of the face of the sealant using a plastic spoon, Popsicle stick, or your finger, backer rod helps to form the sealant into an hourglass shape that optimizes both the elastic and the adhesive qualities of sealants.

Add paint to the caulk tube. *Measure out the specified amount of paint with the supplied syringe, then cap and shake.*

Add activator to the tube and shake. *The activator causes the caulk, which is very liquid until now, to thicken.*

Caulk neatly. *After allowing 30 minutes for the activator to thicken the caulk to a normal consistency, fill the joint.*

Color-matched caulks

Responding to the increasing popularity of factory-painted siding and trim, some manufacturers of caulks and sealants make products in hundreds of colors to match the palettes offered by siding manufacturers. In most cases, these products are purchased from the siding supplier.

Two companies, Red Devil and Sashco, offer tintable caulks. Simply add the specified amount of the paint you're matching to the special caulk tube, shake it like Elvis after a triple espresso, and caulk away. You can even match faded paint by taking a sample to a paint store and requesting a small quantity of color-matched paint.

Color-matched sealants can be a boon when you're caulking materials with high coefficients of expansion. In some cases, although you can easily find a sealant that will handle the movement, no paint is that flexible. The paint will crack and reveal the caulk below. By using a color-matched sealant, the problem goes away.

Although backer rod made of closed-cell foam has few drawbacks and is the type commonly found in retail outlets, backer rod made of open-cell foam can be helpful with moisture-cure sealants such as STPE, polyurethane, and silicone. In dry climates, or in cases when you want a faster cure, open-cell backer rod may allow moisture to reach the back side of the sealant to accelerate a full cure. It's also more malleable than closed-cell backer rod, making it a better choice for irregular joints. That said, ASTM C920 advocates caution when using the open-cell product in horizontal applications because it can wick and retain water.

Bond-breaker tape is harder to find than backer rod; I could only buy it online. In joints too shallow to accommodate backer rod, bond breaker tape applied to the rear or bottom substrate prevents three-sided adhesion. Inside corners are another application, and ¼-in. bond-breaker tape allows very shallow fillets of sealant.

Surface prep is crucial

It doesn't matter which caulk or sealant you use or how much money you spend on it; if you apply it to a dirty, loose, wet, or contaminated surface, it won't adhere. For example, any building material that spent time in a lumberyard warehouse is likely to be contaminated with oily soot from diesel trucks and forklifts. The prep varies with the surface. Wood should be fresh and clean. A light sanding followed by vacuuming or blowing off the dust with compressed air should be sufficient. Painted wood, plastic (such as PVC trim or vinyl windows), and aluminum trim or window cladding need a dusting (microfiber cloth does a great job) and should then be wiped down with a solvent such as MEK, acetone, or mineral spirits. Test the solvent on a small area to be sure it doesn't damage the substrate. Wipe the surface with a solvent-saturated rag, then follow up with a clean, dry rag before the solvent evaporates. Change the rags frequently. Old caulk joints, masonry, and concrete might require scraping, grinding, wire brushing, and a blast of compressed air. Leave no loose material.

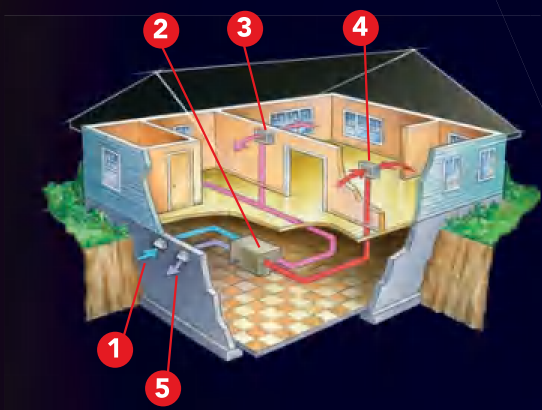
Silicone leaves a residue that not even silicone will stick to. Mechanical cleaning such as sanding or wire brushing is usually required, although Sashco's Charis Babcock reports success in removing silicone with McKanica Silicone Caulk Remover (mckanica.com).

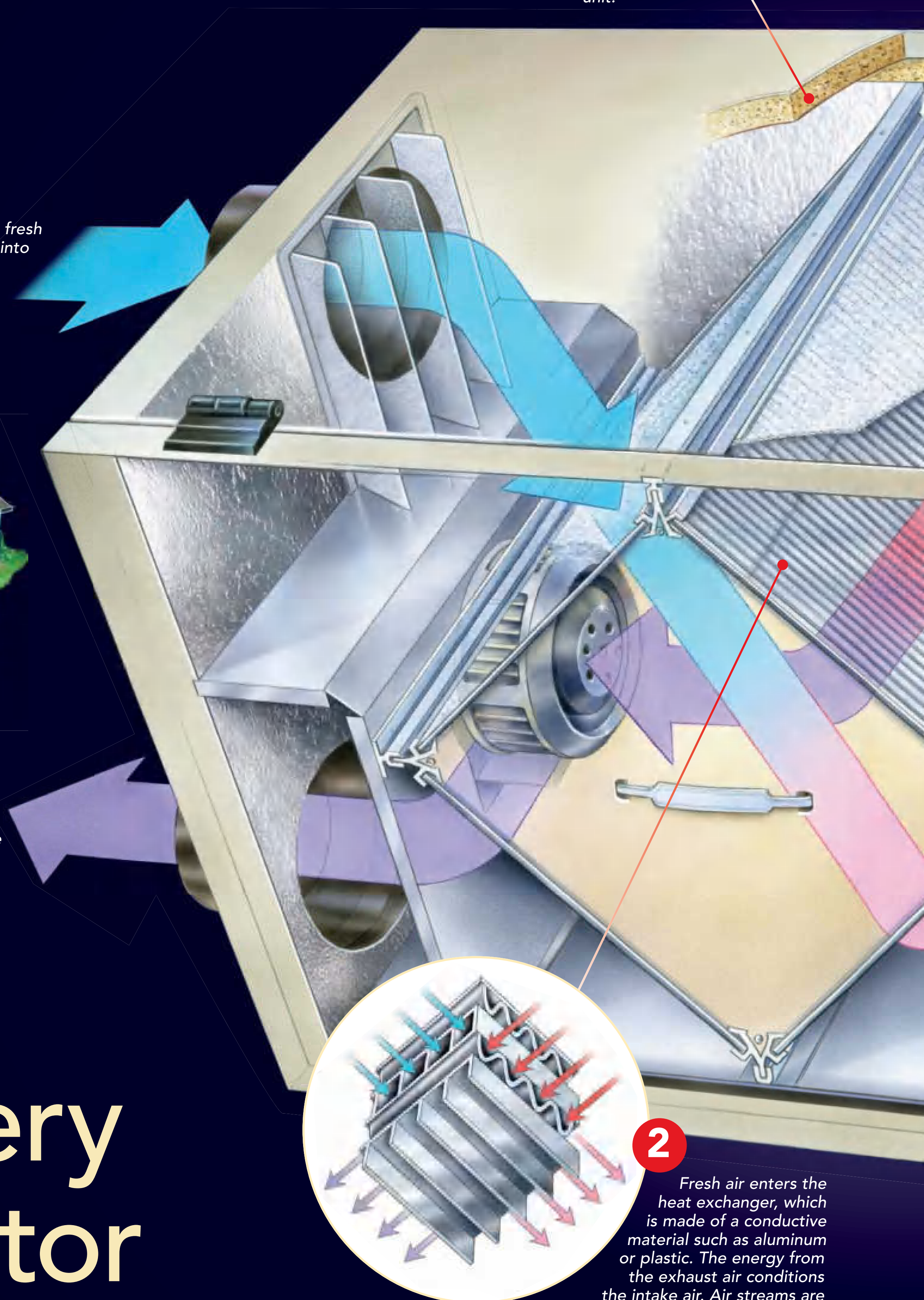
Site conditions matter as much as prep. Many sealants specify a minimum application temperature of 40°F. There are several reasons for this, but perhaps the most important is simply that the surface-wetting characteristics of most substances decreases at colder temperatures. Simply put, most sealants don't stick well to cold surfaces. Additionally, many sealants don't flow well from the tube when they're cold, and inconsistent application can create voids that weaken the bond. Finally, cold temperatures can slow curing, exposing the soft sealant joint to damage. That said, there are some sealants whose manufacturers allow application in cold or wet conditions, but no one claims these conditions are optimal. If possible, wait for a nice day. □

Andy Engel is a senior editor. Photos by Rodney Diaz.

BY ROB YAGID

Heat Recovery Ventilator





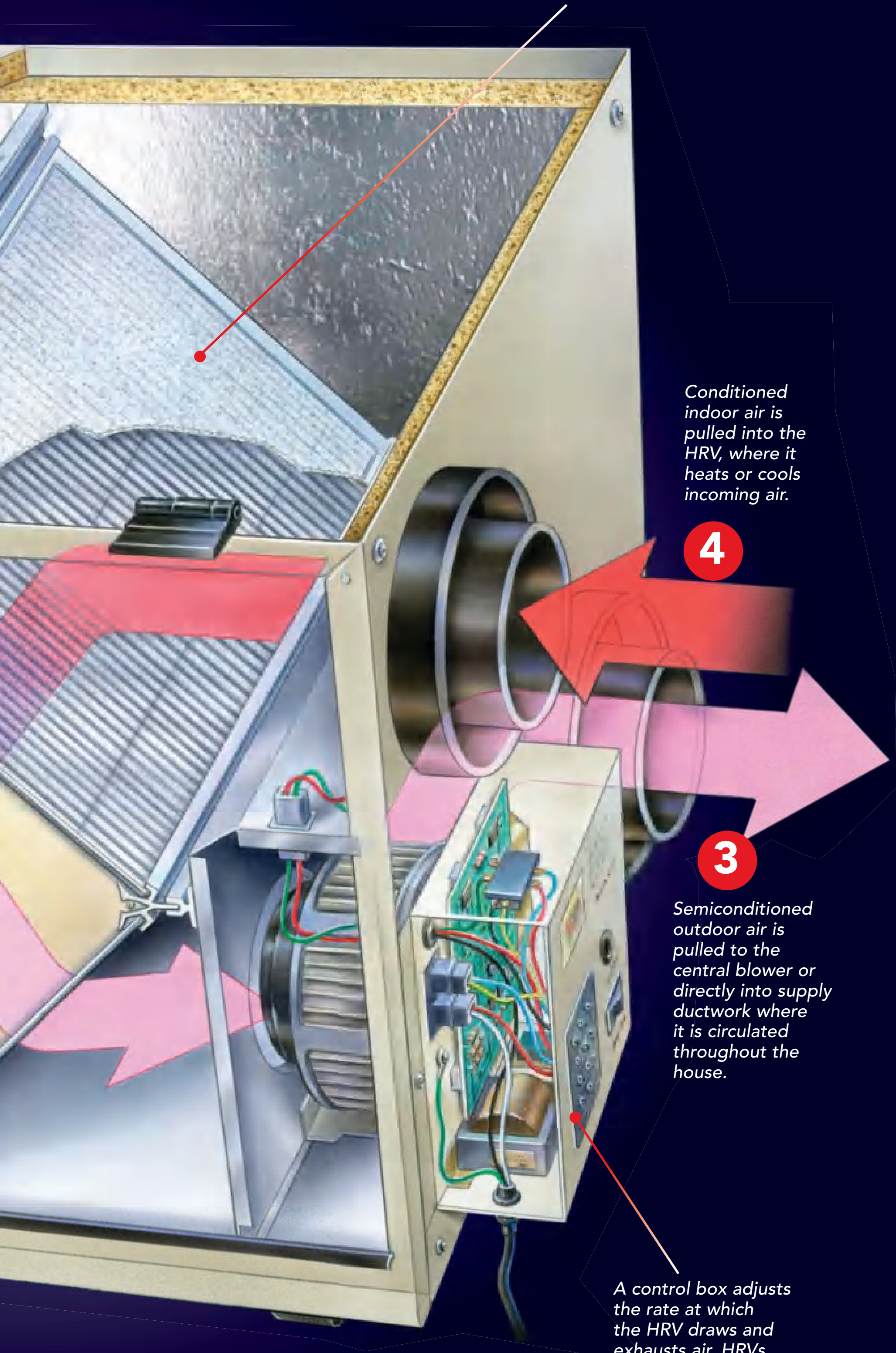
An insulated shell increases the efficiency of the HRV by keeping hot or cold air in the unit.

1 A fan draws fresh outdoor air into the HRV.

5 Indoor air is exhausted outside the home.

2 Fresh air enters the heat exchanger, which is made of a conductive material such as aluminum or plastic. The energy from the exhaust air conditions the intake air. Air streams are separated to keep exhausted contaminants from entering incoming air.

Drawings: Don Mannes



Today's homes are tighter, and that's a good thing. A tight house—one free of air leaks—saves money and reduces the need to scrape the earth of its resources to fuel our lives. However, a tight house can affect indoor-air quality, and not always for the better.

An airtight home has a lower air-exchange rate than a drafty one, which means indoor-air pollutants can more easily accumulate to unhealthful levels. Homes with a low air-exchange rate, usually anything below 0.35 air changes per hour (determined by a blower-door test), need proper whole-house mechanical ventilation. If not designed properly, these systems can be grossly inefficient, pumping conditioned indoor air outside and sending heating and cooling dollars straight out the vent pipe. A well-designed ventilation system uses a heat-recovery ventilator (HRV) to retain a portion of a home's energy while still providing the air exchanges needed to create a healthful home. Here's how it works.

HRVs ARE SMART BUT SIMPLE

An HRV can keep up to 80% of the energy in exhaust air inside a house. Some manufacturers say that HRVs are as efficient at reclaiming the energy in cool air as they are at capturing the energy in hot air. Others say that HRVs are most efficient at capturing heat energy and should be used only in cold climates. In either case, HRVs are most often integrated into balanced whole-house ventilation systems, or are directly ducted, as shown here.

The technology behind an HRV is astonishingly simple. An insulated box houses a couple of fans, some particulate filters, and a heat-exchanging core in which intake and exhaust air flow. As conditioned exhaust air flows through the exchanger, it heats or cools incoming air.

Manufacturers such as Fantech, Carrier, and Honeywell recommend HRVs in most parts of the country, but not all. Fantech, for example, recommends HRVs in all but the hottest, most humid regions. In the Southeast, where it's hot and humid for much of the year, the company recommends the use of an energy-recovery ventilator (ERV). An ERV operates the same way as an HRV, but it has a vapor-permeable heat-exchanging core. The permeable heat exchanger allows a moisture exchange between intake and exhaust air to help control indoor-humidity levels. ERVs, which start at about $800, are only slightly more expensive than HRVs.

Rob Yagid is editor of Fine Homebuilding.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Lessons from the field

A Weatherproof Window

Layers of redundant flashing and sealant ensure that the most expensive part of your house is also the best protected

BY BRIAN KNIGHT

As the building industry tightens up on air-sealing and improves energy efficiency, we need to be more aware of the risks associated with air and water intrusion. Materials that get wet won't dry out as quickly or easily as they used to do in leaky, poorly insulated houses, and many of the materials being used to build houses aren't as resistant to moisture as their predecessors. There's no doubt that with windows accounting for such a large part of the building budget, and being one of the most direct connections to the elements, their installation deserves extra attention.

Windows are complicated, and so is their installation

Compared to solid areas of wall and roof, windows and their interface with the air barriers and water-resistive barriers (WRBs) of a house are complicated and vulnerable. Many builders and designers are confused about best practices, and inferior techniques are rampant. As windows, tapes, sealants, and WRBs evolve, so do the installation guidelines for these products. It's not uncommon for products that are typically used together to have conflicting installation instructions. When in doubt, I follow the window manufacturer's instructions as a bare minimum, and add improvements from there.

The best window installations include redundant layers of protection for keeping water out, incorporate measures for blocking the air movement that can draw that water in through weak spots, and provide an escape path for water that enters before it has a chance to cause damage.

Not all windows are created equal, of course, and it's tough to predict long-term performance. But I don't discriminate or try to predict. Every window I install—regardless of brand, material, or price—gets the same belt-and-suspenders treatment to ensure that air and water leaks aren't going to be an issue.

Aim for waterproof, but plan for leaks

We should always assume that water will find its way into a window opening. Even if the installer does a per-

IT STARTS WITH THE SILL

Create your own sloped sill. *Remove stock from the rough sill to provide drainage in the case of leaks. Draw one line 3 in. from the outside face of the opening, and another about 1⁄4 in. down from its outside edge. To create the slope, use an angle grinder equipped with a rough-grit flap disk.*

Installation

Width plus 12. *Cut a piece of flashing tape 12 in. longer than the width of the opening, which allows 6 in. of tape to extend up each side.*

FHB's PROJECTHOUSE

WATCH THE VIDEOS To see more of this installation, check out our video series at FineHomebuilding.com/projecthouse.

Keep the transition tight. *Use a rafter square to press the tape tightly into the corners where the sill meets the sides of the rough opening, eliminating bubbles under the tape that are vulnerable to puncturing.*

Continuous outside corners. *You can buy flashing tapes made for curves, but they're expensive. Protecto Wrap tape is far more affordable and has enough flexibility to be stretched down onto the sheathing, where I tack it in place with button-cap nails.*

fect job with sealing and flashing, water can still leak through the window unit itself—especially as the materials, transitions, and sealants go through many cycles of expansion and contraction over time. Gravity, capillary action, blowing rain, and pressure differences can push and pull water into these weak points.

Water leaks from windows usually show up at the sill. Because this is the most vulnerable area of a window, it's also where the weatherproofing efforts begin.

As long as there is an air gap in place, a sloped and flashed rough sill is the best way to protect this vulnerable area. Creating a back dam along the rear edge of the sill flashing is an option for ensuring that leaks under the window can't reach the interior of the opening, but I typically don't use back dams unless specifically required by the window manufacturer. I've found that they can complicate rough-opening dimensions, interfere with shimming the window off of the sill pan, and make it difficult to air-seal the bottom of the window.

A piece of bevel siding laid across the rough sill of the opening is the traditional choice for creating a slope, but it requires planning to make sure there is adequate height in the rough opening to fit the siding and layers of flashing tape. Manufactured sill pans are another option and are certainly better than nothing, but I don't like them. The ones I've tried don't have the amount of slope I prefer; can make shimming, air-sealing, and trim installation more difficult; and often are two halves that need to be pieced together and are then never visible for inspection. I prefer to avoid questionable joints or seams in this vulnerable area.

Easy air-sealing opportunity

Regardless of window brand, material, or type, I eliminate the possibility of hidden air leaks through joints and seams in the window frame with vapor-permeable Pro Clima Uni-Tape before the window is installed.

My favorite method is to add the slope right to the rough-sill framing. Sloping the sill after it has been framed eliminates any worry about reducing the height of the rough opening because you're actually enlarging it.

In addition to the sloped sill, the opening is protected with flashing tape, with the weakest interface being the spot where the sill meets the jack studs on each side. There are many ways of cutting flashing tape to fit this situation, but I prefer to stretch the sill flashing around the corner, eliminating the seam altogether.

If the window manufacturer allows it (some require continuous support at the sill), install the window atop spaced shims to increase the drainage and drying potential underneath the window unit and above the sloped, flashed sill.

The biggest obstacle in the drainage path is typically the window's bottom nailing fin. Do not caulk it, do not tape it, do not seal it in any way. Some window manufacturers call for a dashed bead of caulk, but I believe this is just asking for trouble. It's also much easier to tell my crew "No caulk at the bottom" and get consistent results rather than "X lengths of Y diameter caulk with Z amount of space

SEAL THE SIDES,

Sides are simple. *Cover each side of the opening with a piece of flashing tape that bridges the gap between sheathing and framing and that extends down to and over the top of a horizontal piece of the same tape, reinforcing the seam where the sill flashing adheres to the wall. I like Zip System Tape or 3M All Weather Flashing Tape 8067.*

Caulk three sides. *Lay a bead of high-quality caulk along the sides and top of the opening, keeping it close enough to the edge so that the nailing fin will compress it. Never caulk across the bottom. If the corners of the nailing fin are designed to receive a piece of manufacturer-supplied adhesive flashing, skip the caulk in the top corners, as shown here.*

BUT LET THE BOTTOM DRAIN

Bottom first. *Rest the window on the edge of the sill, tip it upright, and slide it straight in against the caulked sheathing.*

Caps make a gap. *To promote drainage, slide caps from button-cap nails under the bottom nailing fin, pressure-fitting one next to each nail. These caps are thick enough to create a gap but not so thick that they will complicate trim installation.*

Reinforce the fin. *Zip System Tape is 3¾ in. wide, which is wide enough for it to be adhered to the sheathing, across the nailing fin, and onto the side of the window frame.*

between them" and then hope for no problems. I like to go even one step beyond by providing a gap behind the nailing fin to promote further drainage.

Deal with air from the inside

In an ideal world, the window unit and any manufacturer-installed jamb extensions have airtight joints, but a builder's best method for assessing airtightness is the blower door, and that means the window is already installed. I'm sure that some manufacturers seal this connection, but it's safer not to assume. I eliminate the possibility of a leaky unit by applying tenacious acrylic-adhesive flashing tape over any seams and joints in the window frame before it's installed. It pays to seal the joints in the rough opening as well to eliminate short circuits or air leakage from surrounding stud cavities. Control the window unit, control the rough opening, and then you can confidently address the space that's left between the two.

Canned spray foam is probably the most common way of sealing between the window unit and the framing. My biggest gripe with this method is that it's difficult to inspect for quality without a blower-door test. On a house I tested recently, I was surprised to find air coming through the spray foam around windows and doors, most likely in the area of a shim, which I've found to be the most vulnerable leakage point.

There are many variables to consider if you're relying on spray foam as an air barrier in this location—the size, shape, and consistency of the bead; whether the can was shaken adequately; if the humidity is suitable; and the texture and temperature of the substrate—so I prefer to think of this spray foam only for insulating purposes. Backer rod and caulk followed by a layer of vapor-permeable flashing tape is what I use as my air-control layers.

I buy several packets of backer rod in diameters of 3⁄8 in., 1⁄2 in., 5⁄8 in., and 3⁄4 in. to accommodate the different-size gaps I typically encounter, and I always use a rod that is slightly fatter than the gap being filled. For gaps smaller than 3⁄16 in., I skip the backer rod and simply caulk the gap. In all cases, I use a high-quality elastomeric or polyurethane sealant made for windows and doors, such as Sonneborne's NP1, Sika's Sikaflex, or Dap's 3.0. These sealants have better adhesion than typical silicone but still allow for plenty of expansion and contraction.

Flashing tape doesn't receive enough attention for use in this location. It's fast, durable, effective, and easy to inspect. Plus, it's the one air-sealing layer that's guaranteed to clear the shims installed around the window.

I prefer a tape that is vapor permeable—I use Pro Clima Uni-Tape—to eliminate it as a potential barrier should any moisture around the window need to dry toward the interior, but I would use something impermeable in a pinch. Tape is typically applied to the rough framing and the jamb-extension edge, but it's important to keep in mind the exposed reveals of the trim when placing the tape.

When followed by careful installation of the drywall, the exterior trim, and the head flashing (all of which are areas that should be handled with care to avoid damaging flashing tapes and air-sealing tapes), you've improved the performance of one of your building's weakest links. □

Brian Knight is owner of Springtime Homes in Asheville, N.C. Photos by Justin Fink.

AIR-SEAL FROM

A conservative bead of foam. *A thin bead of low-expansion spray foam offers limited air-sealing and insulation, but avoid filling the entire cavity, especially toward the bottom, to allow for drainage in the case of water entry.*

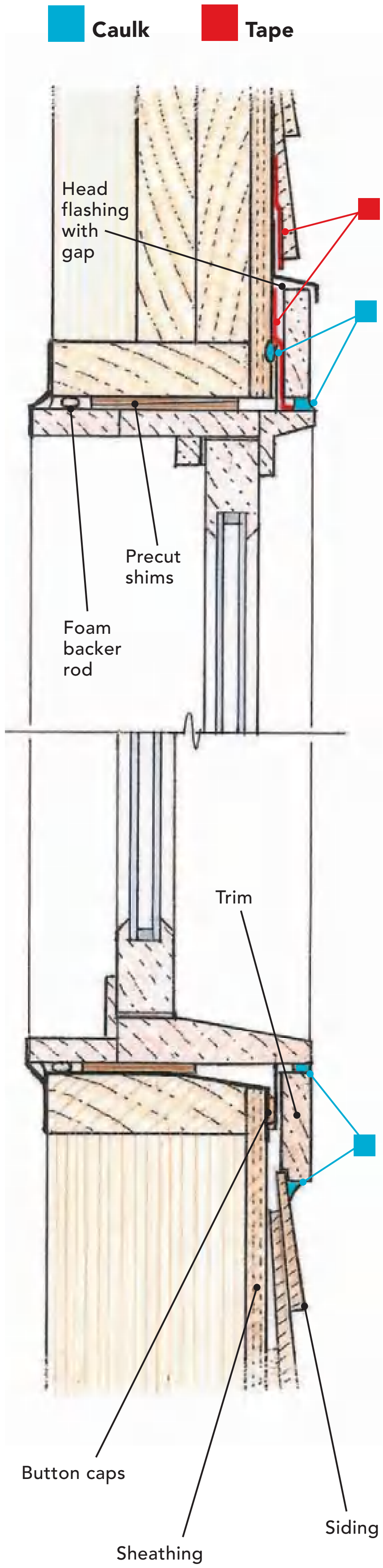
A caulk joint that will last. *Foam backer rod cut and pressed in around the window jamb creates a flexible base for the bead of caulk that follows it. Use a wet finger to smooth the bead against the backer rod, creating the ideal hour-glass shape that allows the sealant to expand and contract without cracking or debonding.*

Drawing: Vince Babak

M THE INSIDE

Tape is the innermost air-seal. *Applied so that it bridges the gap between rough frame and window jamb, flashing tape provides an easily inspectable air barrier that, like the backer rod and caulk, isn't affected by the shims along the four sides of the window.*

Finish strong on the exterior



The exterior weatherization—the tape, the head flashing, the caulk, and their integration with the trim and the siding—is the last step in a well-detailed window installation. It's fairly common for people to unknowingly seal the crucial water exit points while missing some of the important leak-prone areas. Here are some general guidelines.

- Wherever there is flashing or a shingle-style transition in which one piece laps over another, such as clapboard over the head flashing, don't caulk. Any transition other than a lap, such as a butt joint where siding meets trim, should be caulked.
- Whatever the material, seal the top and bottom pieces of trim to the nailing fin or window frame to prevent water running behind it, even if the wall includes a vented or ventilated rain-screen assembly.
- Don't let installers place siding directly on top of the head flashing, and never add caulk in this location. Space the siding off the flashing to achieve a gap of ⅛ in. to ¼ in.; otherwise, paint can seal this water-drainage pathway.

Air-sealing Can

Common air-sealing enclosures can lead to

BY LARRY ARMANDA

I've been an electrical contractor and a building-performance professional for more than 35 years. Over the past two decades, I've read countless articles in *Fine Homebuilding* and other magazines that describe the use of enclosures built from drywall and foam insulation to air-seal can lights in attics. Sealing these notoriously leaky fixtures—which waste energy, allow moisture into the attic, and contribute to ice dams—is a good idea. Unfortunately, the way many builders and weatherization professionals approach the work is potentially dangerous. The problem is that heat generated by the lightbulbs and trapped within the enclosures can melt the wiring's plastic insulation, leading to arcing and fire.

Air-sealing can lights safely isn't a new concern of mine. I did my first research in 2001 and published the results in *Home Energy,* a magazine for the weatherization industry.

I recently completed new research into the subject. This time I built a more comprehensive test rig that mimicked common ceiling construction, and I tested five types of air-sealing enclosures: three homemade versions (2-in. polystyrene insulation, 1-in. foil-faced polyisocyanurate insulation, and ⅝-in. drywall) and two manufactured enclosures (CanCoverIt and Tenmat). In turn, I installed these enclosures over fixtures (with the can light's thermal safety switch bypassed so that I could determine the maximum temperature inside the various enclosures) and taped them to the drywall ceiling with foil tape, similar to how weatherization crews would install them.

The author tested seven different bulbs in five air-sealing enclosures.

Attics add to the problem

Summertime attic temperatures prevent heat within the enclosure from dissipating, which adds to the risk of shorted wiring and fire. To simulate the worst-case scenario, I built a large insulated box over my test-light setup and heated it to 135°F with a 300w lightbulb. (Attics in my part of Pennsylvania routinely get this hot on summer days.) I ran a total of 35, 12-hour tests with seven different lightbulbs in each of the five enclosures. I recorded the temperatures inside the enclosures in three locations and inside my "attic" test space with a four-channel HOBO data logger. What I found is alarming.

The highest temperatures recorded approached 250°F with a standard incandescent bulb. Although this isn't the bulb that these fixtures are designed for, weatherization crews routinely find them in can lights. Even with the correct bulb, though, temperatures inside the boxes routinely exceeded 160°F, high enough to degrade the insulation on older versions of nonmetallic-sheathed (NM) cable, which

AN ACCIDENT WAITING TO HAPPEN

Heat generated by the bulb and trapped within the enclosure can have a dangerous effect on the surrounding materials. There are four potential problems with the way many can lights are air-sealed.

Fixture

Older non-IC can lights don't have a thermal safety switch, so temperatures inside an enclosure can climb until the foam box melts or the insulation on the wires melts or catches fire.

Wiring

Nonmetallic-sheathed cable installed before 1984 is rated for 140°F. Testing reveals that temperatures inside the box can reach 171°F, even with the correct 65w PAR 30 incandescent bulb.

Enclosure

Polystyrene insulation starts to melt at 167°F, yet internal temperatures can exceed 170°F with the correct bulb and approach 250°F when a standard A19 Edison-style bulb is installed.

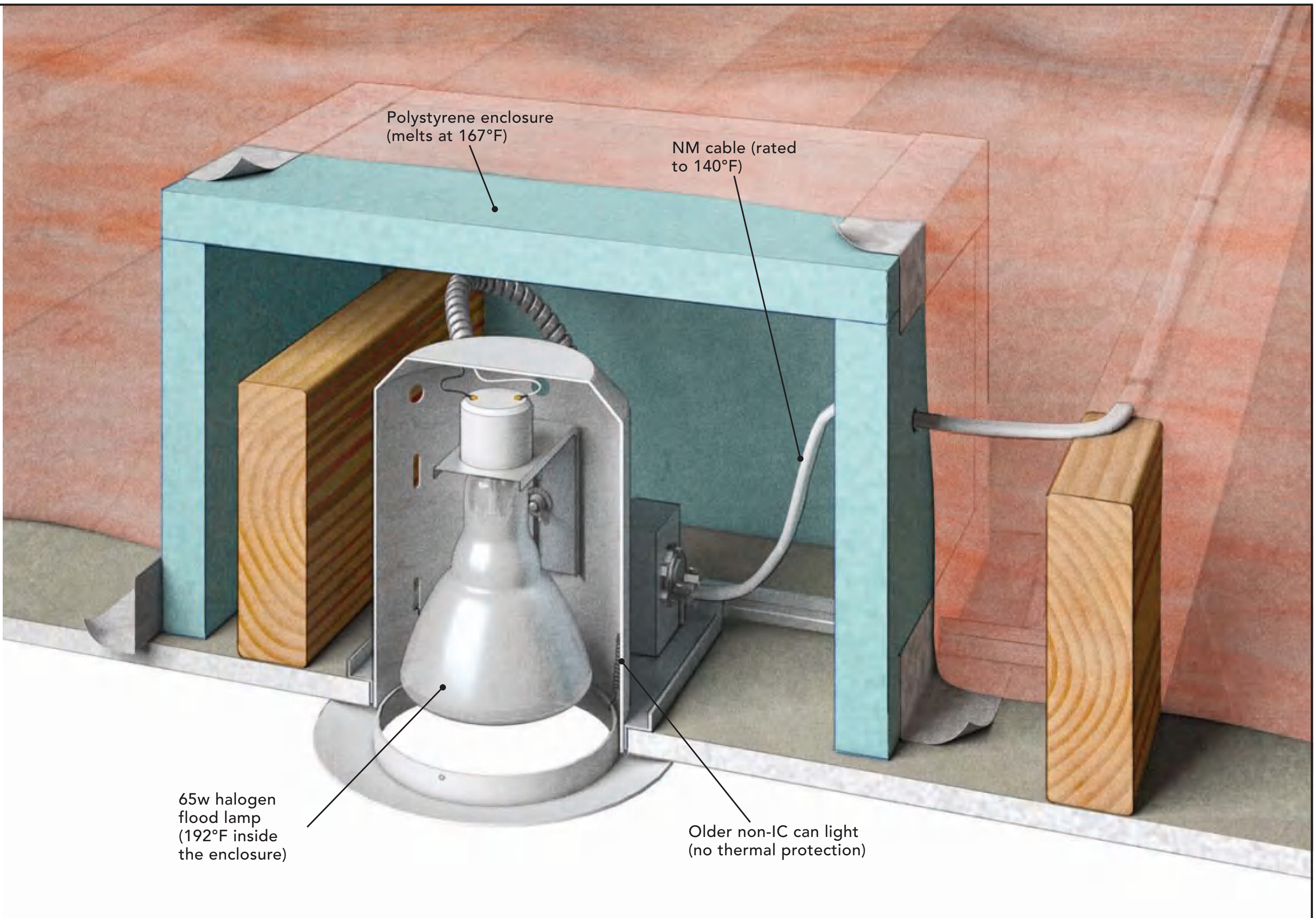
Bulb

Weatherization crews and electricians routinely find the wrong bulbs installed in ceiling-mounted can lights, but even the correct bulb can make the inside of the enclosure over 170°F—too hot for older wiring.

Photos this page: Patrick McCombe. Drawings: John Hartman.

Lights Safely

melted foam, shorted wiring, and even fire



Is your wiring safe?

NM cable This cable is rated to 140°F and was in use from the mid-1960s through the mid-1980s. It looks like modern NM-B cable, so you need to read the sheathing to tell the two apart.

NM-B cable Introduced in 1984, NM-B cable is rated to 194°F. It's the only safe wire for inside can-light enclosures. The NM-B designation is printed or embossed on the cable's sheathing.

is rated to 140°F. This type of cable was installed from the mid-1960s until 1984.

I also found that foam enclosures could get hot enough to melt when the lights had halogen flood lamps or conventional Edison-base lightbulbs. In some cases, temperatures were above the foam's melting point of 165°F, but not quite hot enough to trip the light's thermal safety switch, which activates at 194°F. This switch is included on modern can lights to prevent overheating.

Older cans don't have a thermal switch, so when they're enclosed, it's conceivable they would keep getting hotter until either the wiring or the enclosure melted. Although I didn't see any melted wires during my comparatively brief periods of testing, I've seen NM cable that's exposed to long-term heat from early fluorescent ballasts: The inner insulation gets brittle and melts, leading to shorts and electrical fire. I did, however, see evidence of localized melting in the extruded-polystyrene enclosure I built. This enclosure was in service only for 12 hours at a time. You can imagine what might happen if the light was left on with the wrong bulb for a few days or more.

Building a safe enclosure

Given the problems with conventional methods of air-sealing can lights, I've come up with what I consider the safest way to do it. For starters, I recommend a manufactured Tenmat enclosure (tenmat-us.com), which is made from mineral wool and is fire resistant. You also can use drywall enclosures. They resist heat sufficiently, although they are more susceptible to mold growth in homes with high humidity because the paper facing is a good food source for mold.

Make sure the wiring that supplies the can light is designated NM-B (see "Is your wiring safe?" p. 101), which is rated to 194°F. If the wiring is not NM-B, install a junction box about 18 in. away from the fixture, and use a short length of modern NM-B to connect the older wire and the fixture. Put the junction box on a mast so that it's not buried in insulation and is easy to find for any future work. Finally, use high-quality UL-181 foil duct tape or a fireblock-type spray foam to seal the enclosure to the drywall ceiling.

Choose the right bulbs

I found that you can keep the fixture sufficiently cool and safe by using the correct reflector bulbs. Unfortunately, the right bulb is often replaced with an Edison-style or halogen reflector bulb when the correct bulb burns out. The best way to prevent the installation of the wrong bulb is to install an LED can-light conversion kit. These conversion kits ($25 to $35) have life spans of about 50,000 hours (almost four years of nonstop use), making it unlikely that someone will swap one out for a potentially dangerous incandescent light.

Many of these retrofit kits claim to be airtight, so you might be tempted to install one and forget the can-light enclosure altogether. Unfortunately, when researchers tested supposedly airtight kits in the past, they found that most were improperly installed, reducing their effectiveness. I don't know of any research that's been done to confirm the airtightness of modern LED retrofit kits. Until we know for sure, I think appropriately constructed can-light enclosures are still the best solution, short of removing the can lights altogether. □

Larry Armanda is a building-science trainer and consultant. His company, Therma View Energy Consultants, is in Williamsport, Pa. Photos by Dan Thornton, except where noted.

EVEN THE RIGHT BULB CAN BE DANGEROUS

75w A19 standard bulb

This Edison-style incandescent bulb generated the highest temperatures inside all five enclosures. It produced 245°F in the polystyrene cover, well above the material's melting point of 167°F. It raised the temperature to 246°F inside the polyisocyanurate and Tenmat enclosures. The CanCoverIt reached 224°F, and the drywall enclosure reached 216°F. All of these temperatures would have tripped the thermal safety switch and easily exceed the rating of NM cable and even modern NM-B cable.

65w PAR 30 halogen flood

This common bulb produced 192°F in the polystyrene, polyisocyanurate, and Tenmat enclosures, which is very close to the point where the fixture's thermal safety switch will activate (194°F), turning off the light. These temperatures also easily exceed the rating of NM cable. The CanCoverIt (183°F) and the drywall enclosure (164°F) were cooler, but still too hot for NM.

65w PAR 30 standard flood

This is the traditional bulb for common can-light fixtures. Even so, the air inside the polyisocyanurate enclosure reached 175°F. The Tenmat was 173°F, and the polystyrene and CanCoverIt reached 167°F, which is very close to polystyrene's melting point. At 156°F, the drywall enclosure was the coolest. All of the enclosures reached temperatures that exceed the temperature rating of NM cable but that are below the activation point of the thermal safety switch.

22w LED lamp

Even though many people think of LEDs as generating little heat, the polyisocyanurate enclosure reached a high temperature of 145°F. The Tenmat was 144°F, and the CanCoverIt was 143°F. All of these temperatures were above the NM-cable rating but well below the point where the thermal safety switch is triggered. The lowest temperatures were recorded with the polystyrene and drywall enclosures, which were 140°F and 134°F, respectively.

13w Utilitec LED trim kit

Of the bulbs tested, this is the safest option. It generated 123°F inside the CanCoverIt, 118°F inside the polyiso enclosure and the Tenmat, and 117°F inside the polystyrene. The lowest temperature was recorded inside the drywall enclosure (106°F). All of these temperatures are safe for NM cable and well below the activation point of the thermal safety switch. This kit is rated for 50,000 hours, so it's unlikely that it will be swapped for an incandescent later.

FOUR FACTORS THAT MAKE A SAFE ENCLOSURE

Fixture

Modern can lights have a thermal switch that turns off the fixture when the temperature reaches 194°F. It's an important safety device, but it's set too high to protect older wire from the heat trapped within the enclosure. Older can lights often don't have this safety feature, so they should be replaced with modern versions before any air-sealing occurs.

Wiring

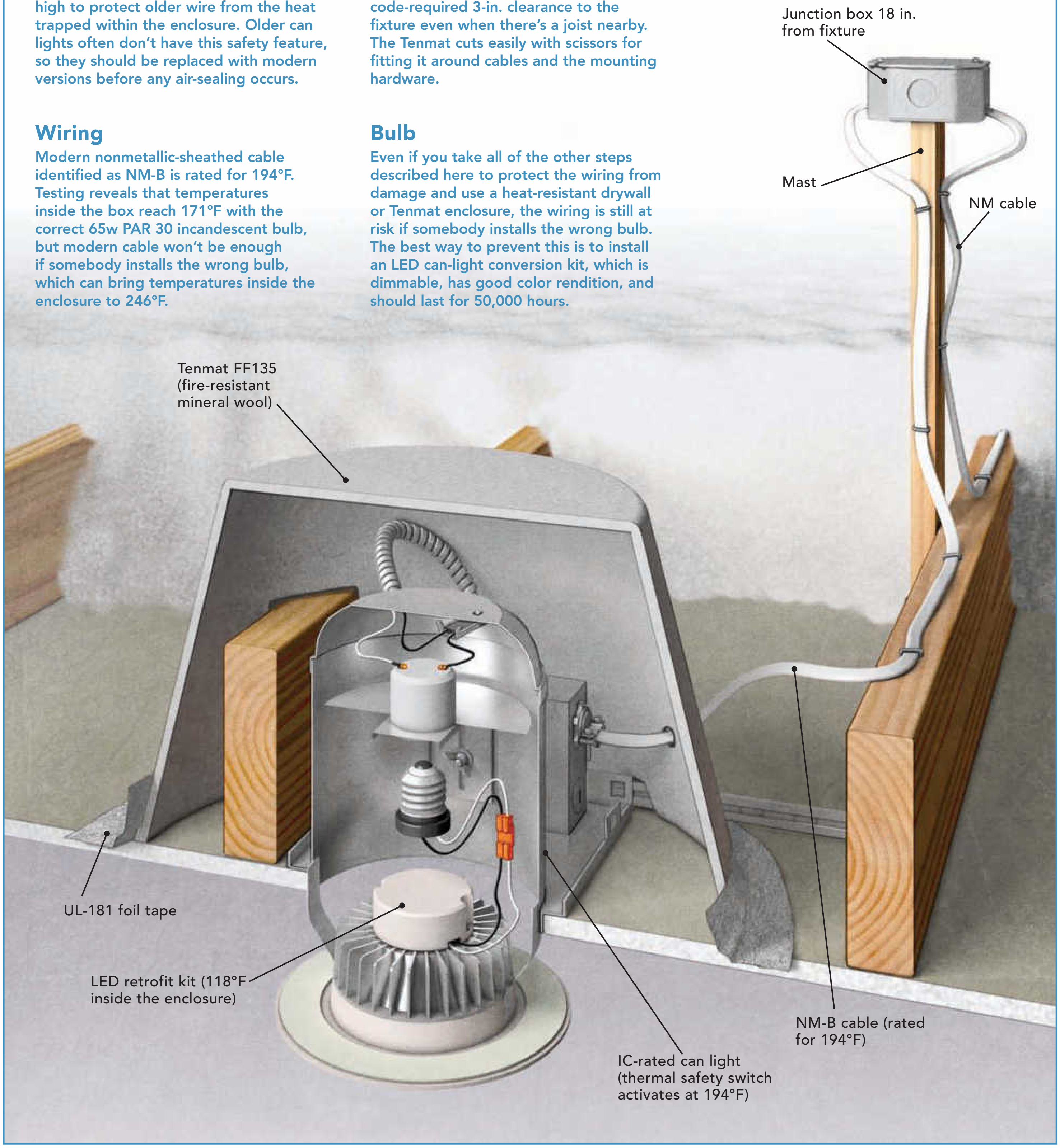
Modern nonmetallic-sheathed cable identified as NM-B is rated for 194°F. Testing reveals that temperatures inside the box reach 171°F with the correct 65w PAR 30 incandescent bulb, but modern cable won't be enough if somebody installs the wrong bulb, which can bring temperatures inside the enclosure to 246°F.

Enclosure

Made from mineral wool, the Tenmat enclosure won't melt like polystyrene insulation, and the larger version (model FF135) is big enough to maintain the code-required 3-in. clearance to the fixture even when there's a joist nearby. The Tenmat cuts easily with scissors for fitting it around cables and the mounting hardware.

Bulb

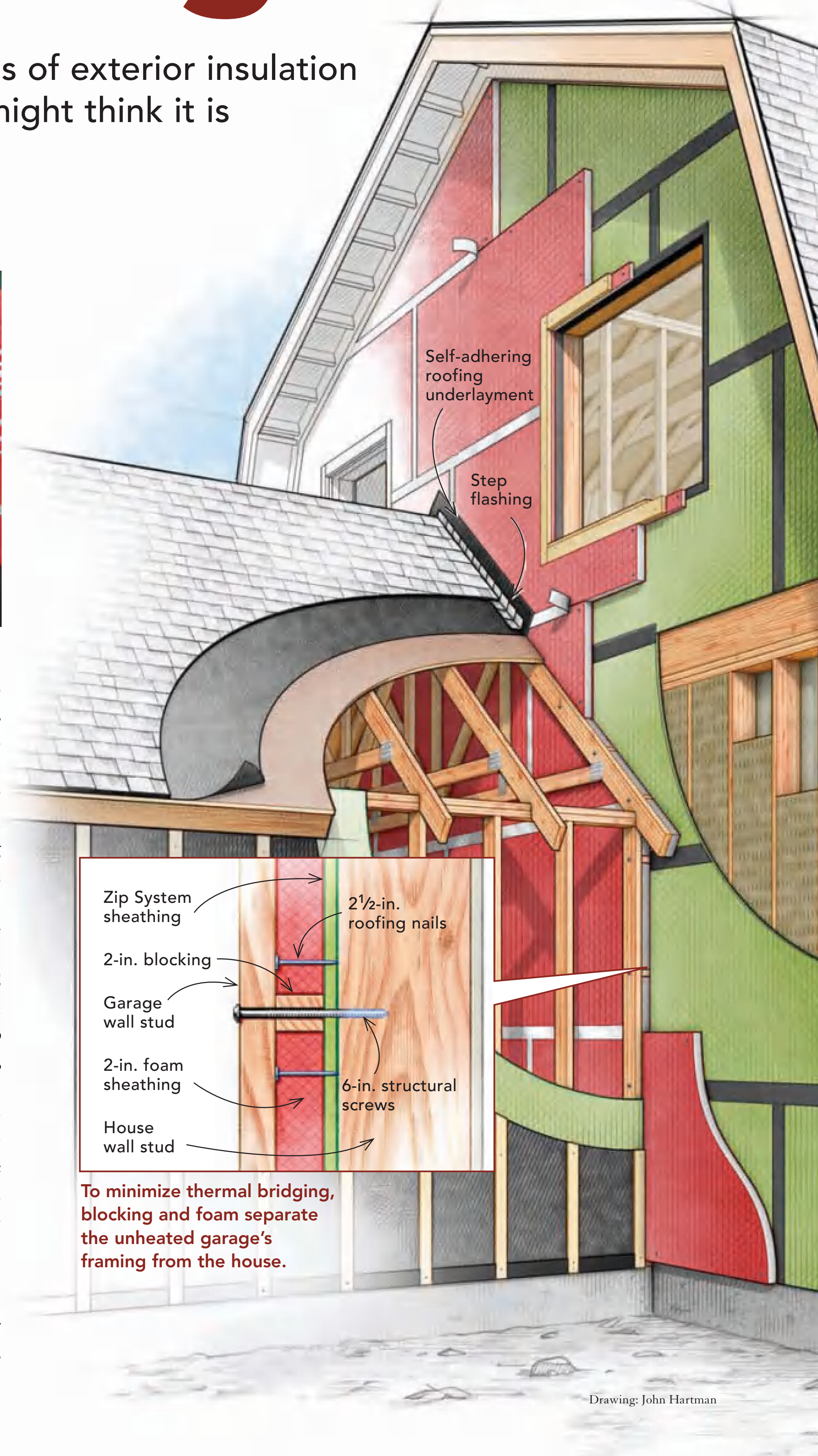
Even if you take all of the other steps described here to protect the wiring from damage and use a heat-resistant drywall or Tenmat enclosure, the wiring is still at risk if somebody installs the wrong bulb. The best way to prevent this is to install an LED can-light conversion kit, which is dimmable, has good color rendition, and should last for 50,000 hours.



Detailing Walls

Navigating the challenges of exterior insulation isn't the nightmare you might think it is

BY STEVE DeMETRICK



To minimize thermal bridging, blocking and foam separate the unheated garage's framing from the house.

Drawing: John Hartman

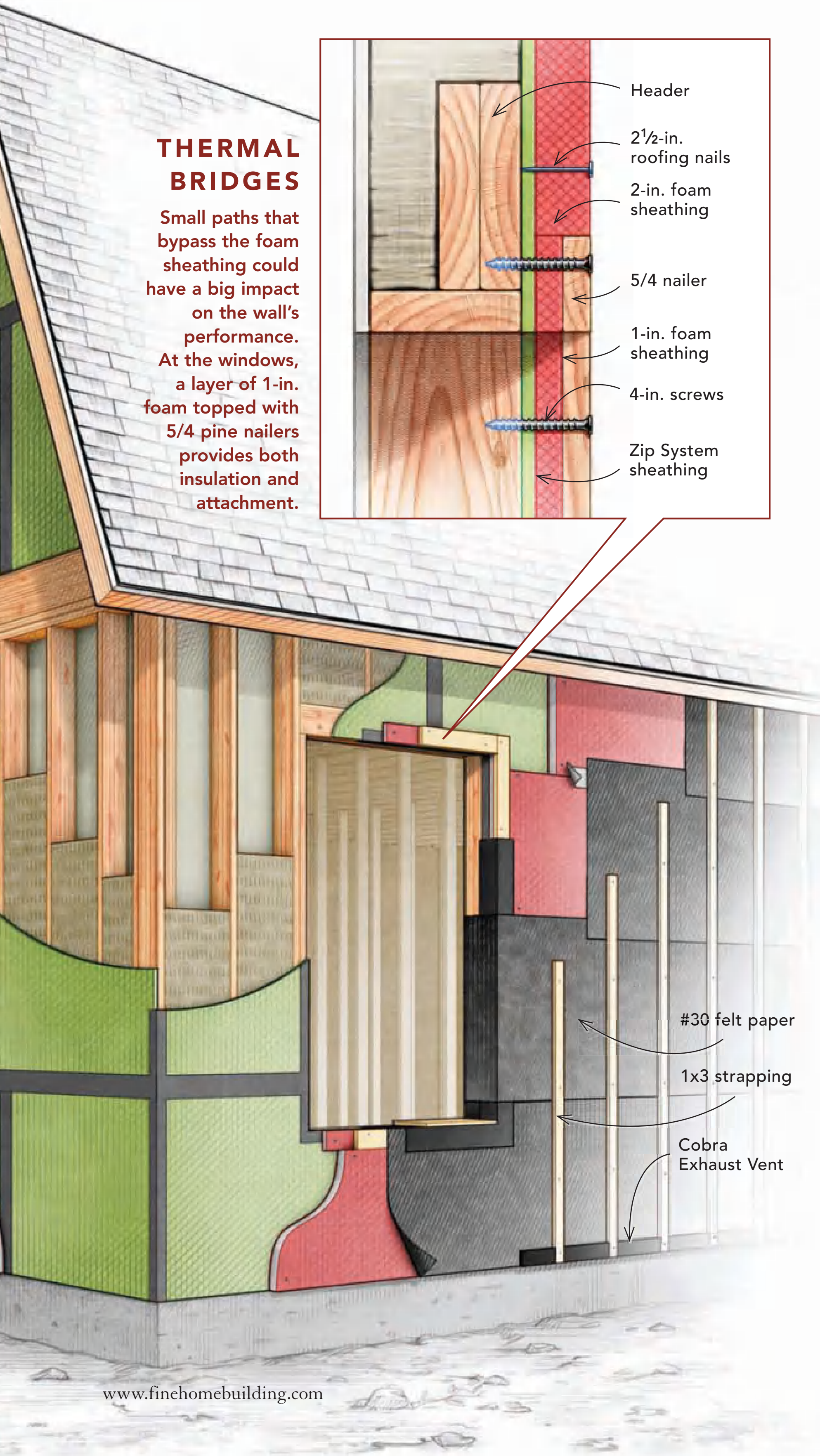
Wall construction has changed dramatically since I started in the trades 20 years ago. The 2x4 walls insulated with R-13 fiberglass batts that everyone built back then don't come close to complying with today's energy code in climate zone 5, where I live. And even with today's stricter codes, building just to code is like settling for a D in school. A house that only meets the minimum standard is the worst that can legally be built.

On this house, the combination of 2-in. foil-faced polyisocyanurate exterior foam and 6 in. of fiber insulation create a high-performance wall that exceeds the IRC requirements. But even meeting the minimum wall R-values required by the new energy code can be hard to achieve with cavity insulation alone. In climate zone 5, walls are required to be at least R-20, and standard batts yield R-19. In cold climates, exterior insulation in addition to the cavity insulation is becoming a de facto code requirement. But there are pitfalls, including moisture condensation, detailing challenges around windows and other penetrations, and the lack of a solid base for attaching the siding. Here's how I navigate them.

Walls that make sense

As a consultant on this build, I worked with carpenter Andrew Gallant of Gallant Builders on the wall details.

with Rigid Foam



THERMAL BRIDGES

Small paths that bypass the foam sheathing could have a big impact on the wall's performance. At the windows, a layer of 1-in. foam topped with 5/4 pine nailers provides both insulation and attachment.

Our combination of foil-faced foam and Zip System sheathing has created walls that are essentially impervious to moisture on the outside, meaning that they can only dry inward. To allow this, the wall cavities will be insulated later with unfaced fiberglass or mineral-wool batts, and the interior finish will be gypsum board, plaster, and vapor-permeable latex paint, all of which allow free movement of water vapor.

Because moisture generally moves from warm locations to cool ones, in this predominantly heating climate, the vapor drive is outward for most of the year. That makes controlling interior moisture a critical component of the house's system. Otherwise, water could condense on the back of the sheathing, causing rot. Accordingly, interior moisture will be managed by a combination of timed bath fans, kitchen exhaust fans, and an energy-recovery ventilator (ERV). Not too many years ago, the standard approach would have been to use an interior Class I vapor retarder such as polyethylene sheeting. Today we know that having vapor-impermeable surfaces on both sides of a wall traps any moisture that does sneak in, often leading to rot.

In addition to keeping out exterior moisture and air, being able to dry, and reducing thermal conductivity, walls also should be simple to build. A goal in all of my projects is to detail walls so that carpenters can build with familiar materials and tools. The walls shown here are a good example of that approach. The studs are 2x6s on 16-in. centers. The Zip System sheathing, with its seams carefully taped, doubles as the air barrier. Although the sheathing could also function as the house's water-resistive barrier (WRB), it was easier to detail the wall so that the WRB is just behind the siding.

Continuous foam significantly reduces thermal bridging through the studs and wall plates, increasing the total R-value of the wall. The assembly needs to be thought through before framing begins. The first step is to locate on the plans exactly where the foam-insulation plane is located and then identify any places where there are connections that might break the continuity of the foam.

Installing the foam

The 4x8 sheets of 2-in. polyisocyanurate are fastened to the wall sheathing with 2½-in. roofing nails. Only a few nails per sheet are needed because 1x3 strapping applied later provides the real holding power. There are many ways to cut the foam. My tool kit includes a Festool track saw, a Japanese pull saw, and a Tajima retractable knife whose long blade is handy for making quick cuts when

DETAILING ROUGH OPENINGS

Sheathing with foam is mostly dirt simple, with windows and doors being the trouble spots. The main things to keep in mind are providing solid nailing while avoiding creating a thermal bridge, and providing adequate flashing to keep out water.

Create a thermal break. *Nail foam strips 1 in. thick and 3½ in. wide around the opening.*

Install nailers. *Screw rough-pine 5/4x3 nailers over the 1-in. foam to build the assembly out to the plane of the main 2-in. foam insulation.*

Butt the wall foam to the build-out. *Installation of the rest of the insulation is simply a matter of cutting to fit and fastening with 2½-in. roofing nails.*

Add a solid sill. *To create a base for windows and doors, fasten a piece of ¾-in. sheathing to the bottom of the rough openings.*

Proceed normally. *With solid nailing established, installing windows or doors and integrating them with the WRB and the flashings is the same as on any other job.*

Photos facing page: Katelyn Gosselin

I'm not standing at the cut table. The foam seams are taped with 3-in. foil-faced tape.

Windows and doors are the biggest stumbling block with exterior foam. You need solid material at the surface to attach to. Building out to the plane of the foam with solid blocking would create a thermal bridge around every opening. Instead, Gallant nailed 3½-in.-wide rips of 1-in. foam around the windows, followed by 5/4x4 rough pine screwed to the framing through the foam, creating a thermally broken attachment point for the windows and doors. The 2-in. foam butts to this assembly. To create a solid base for supporting the windows and doors, Gallant screwed ¾-in. sheathing to the bottoms of the rough openings, which were built ¾ in. taller to accommodate the thickened sill. With this treatment, the window and door openings can be flashed just as on a typical wall.

Felt paper keeps out the rain

The most critical element of any wall assembly is the WRB and its flashings. On this project, the taped Zip System sheathing and the taped foam act as redundant WRBs, but the primary WRB is #30 felt paper and self-adhering flashings that go over the foam. From remodeling century-old oceanfront homes that stayed dry, I know that properly lapped and flashed felt paper works over the long term. I'm not so sure about WRBs that rely on the adhesion of tape to keep out water.

The felt paper is attached with 2½-in. roofing nails and is lapped shingle-style over all of the window and door flashing, as well as over the roof step flashing. To avoid having to hand-drive pounds and pounds of roofing nails to hold the felt paper if the wind kicked up, Gallant worked in small sections, installing the felt paper and following up immediately with strapping.

With very tight houses, it's important to seal the small holes made for items such as wires and pipes. On a Passive House I built, a first-floor window leaked significantly during a rainstorm through a 1-in.-long tear in the flashing tape. In a typical house, that wouldn't result in a pronounced leak, but this house was extremely airtight. The problem was located in the second-floor wall, where two 6-in. holes for the ERV intake and exhaust hadn't yet been connected. The wind depressurized the house through these holes. Because the house had so few leaks, enough negative pressure was created to suck water in.

With that in mind, wires for outside lights were taped to the sheathing prior to the installation of the foam. Once taped, wires were routed down the face of the wall a few inches and to the fixture or outlet to prevent water from following the wire into the wall. Larger holes for pipes or ventilation fans were first air-sealed at the sheathing with EPDM gaskets (foursevenfive.com) and then flashed to the foam with 3M's All Weather Flashing Tape.

The final step before installing the siding was to attach the 1x3 vertical strapping over the foam to provide nailing for the siding and trim. The strapping is fastened through the foam and the sheathing to the studs with 5-in. screws. The ¾-in. space formed by the strapping creates a generous drainage gap for water that gets behind the siding. The airspace also will ventilate the siding so it can dry evenly, resulting in a more durable installation and paint job. I know of similar houses that have gone 15 years without repainting. To keep vermin out of the space while allowing airflow, Gallant nailed Cobra Exhaust Vent between the strapping at the bottom of the wall. □

Steve DeMetrick is a builder and residential energy consultant in Wakefield, R.I. Photos by Andy Engel, except where noted.

There's more than one way to skin a house

Of the four common types of insulating sheathing, the foil-faced polyisocyanurate used here offers the highest R-value per inch (R-6.5). In addition, it's readily available and practically vapor impermeable (it's a Class I vapor retarder). Extruded polystyrene (XPS) is also readily available, is slightly vapor permeable (Class II), and offers an R-value of R-5 per in. Expanded polystyrene (EPS) may be a little harder to find, has an R-value of around R-4 per in., and is several times more vapor permeable than XPS (although it still falls within the Class II range). Finally, there is mineral-wool board, a denser material than mineral-wool batts. Mineral wool is open to vapor transmission and has an R-value of about R-4 per in.

Foil-faced polyisocyanurate R-6.5 per inch

Extruded polystyrene R-5 per inch

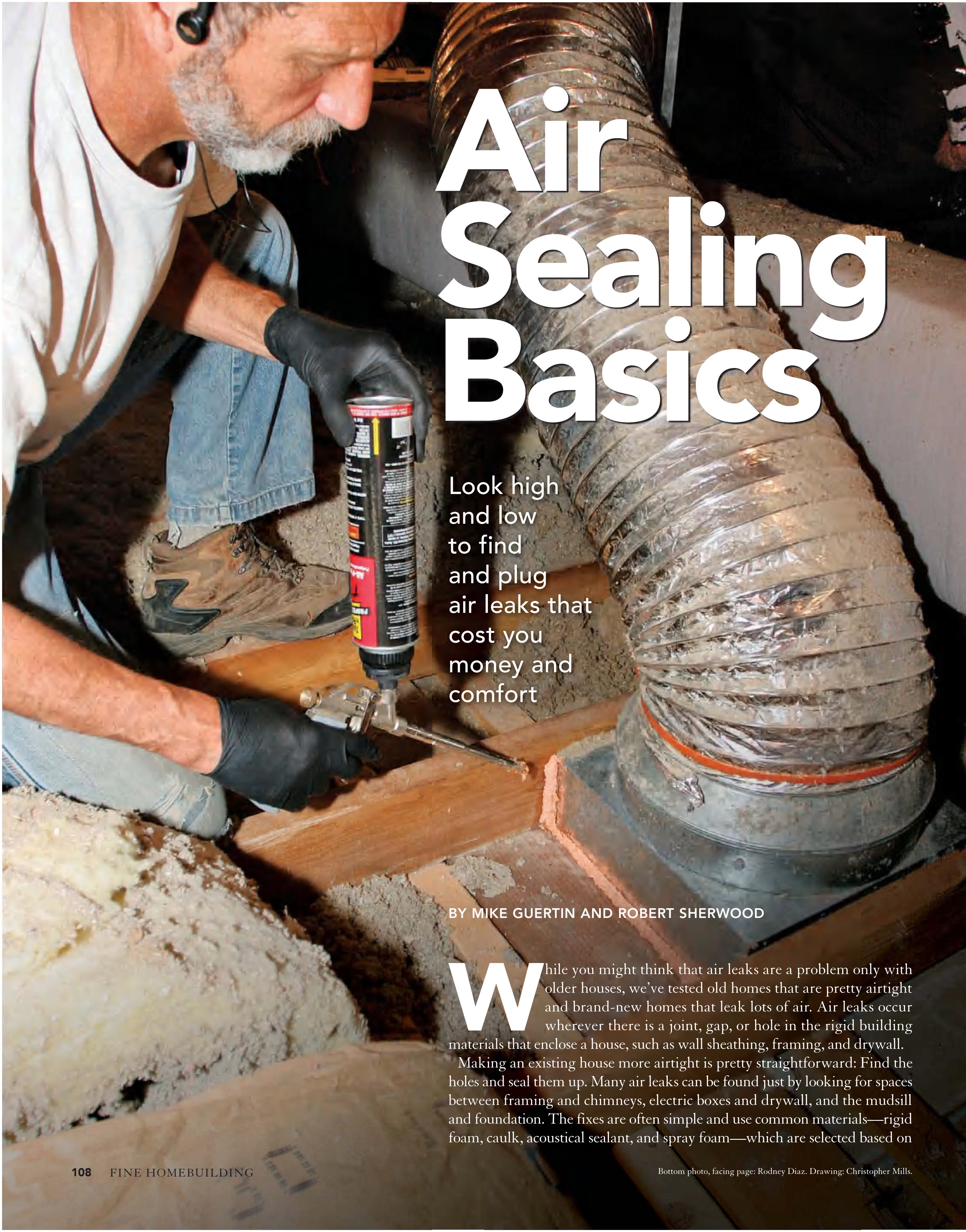
Expanded polystyrene R-4 per inch

Mineral wool R-4 per inch

Insulation ratio determines vapor-retarder type

When designing a wall, think about the risk of condensation within the wall cavity. The inside of the sheathing must be kept warmer than the dew point so that moisture doesn't condense there, so the ratio of exterior insulation R-value to cavity insulation R-value is critical. Either the exterior insulation needs to be sufficient to keep the sheathing above the dew point, or the cavity insulation needs to leak enough heat to achieve the same end. Colder climates require higher ratios and/or less permeable vapor retarders. To find the insulation ratio of a wall, divide the exterior R-value by the cavity R-value. In the chart at left, use the insulation ratio and the climate zone to determine whether a vapor retarder is needed, and if so, what class to use. For more information, see p. 24 of "Designing for Durability" (pp. 20-24).

Climate zone	Class II interior vapor retarder	Class III interior vapor retarder
1 to 3	No limit	
4	0.2	
5	0.2	0.35
6	0.25	0.5
7	0.35	0.7



Air Sealing Basics

Look high and low to find and plug air leaks that cost you money and comfort

BY MIKE GUERTIN AND ROBERT SHERWOOD

While you might think that air leaks are a problem only with older houses, we've tested old homes that are pretty airtight and brand-new homes that leak lots of air. Air leaks occur wherever there is a joint, gap, or hole in the rigid building materials that enclose a house, such as wall sheathing, framing, and drywall.

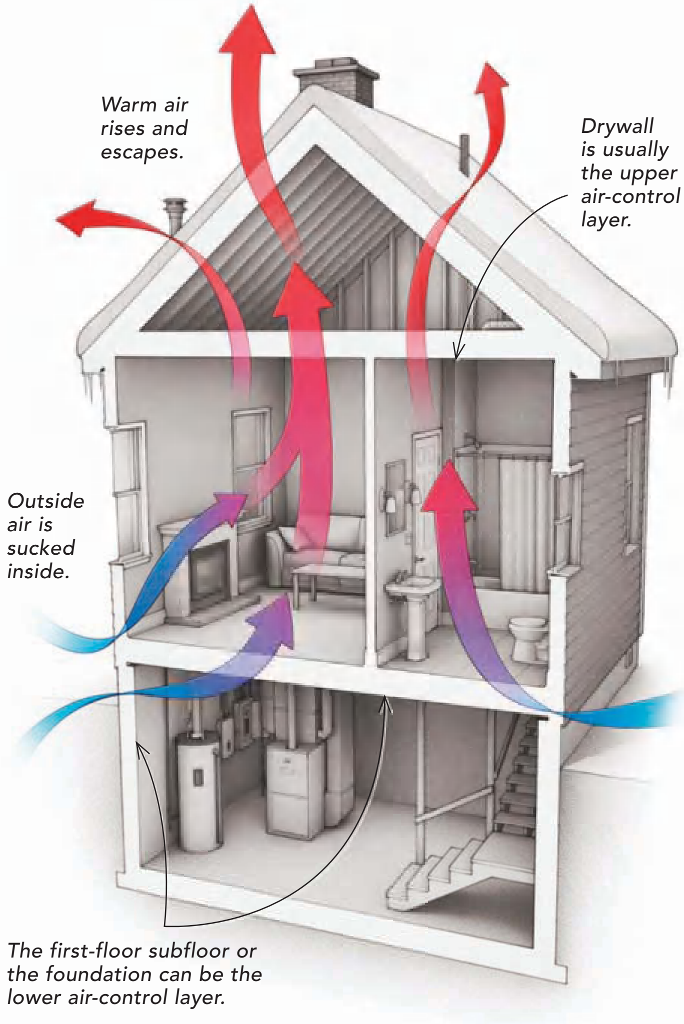
Making an existing house more airtight is pretty straightforward: Find the holes and seal them up. Many air leaks can be found just by looking for spaces between framing and chimneys, electric boxes and drywall, and the mudsill and foundation. The fixes are often simple and use common materials—rigid foam, caulk, acoustical sealant, and spray foam—which are selected based on

Bottom photo, facing page: Rodney Diaz. Drawing: Christopher Mills.

THE PATH TO A TIGHTER HOUSE

HOW HOUSES LEAK AIR

Warm air rises, creating a zone of higher pressure at the top of a house that forces air out of any hole it can find. This escaping air creates a zone of lower pressure at the bottom of the house that sucks in air through holes and cracks. This is the stack effect. Sealing leaks at the top and bottom of the house is the most effective approach for stopping it. The colder it is outside, the stronger the stack effect, so air-sealing can have a big impact in cold climates (zones 4 to 8) and a lesser one in mixed climates (zone 3). It is not as important in warm climates (zones 1 and 2).



TWO TOOLS FOR FINDING AIR LEAKS

SMOKE GENERATOR
The Wizard Stick works like an old Lionel locomotive, generating vapor by heating glycerin. It runs on 6 AA batteries and costs $25 from Amazon.com.

HOMEMADE BLOWER DOOR
Some scrap plywood and a $150 fan create a blower door that's adequate for finding air leaks.

THREE MATERIALS FOR STOPPING AIR LEAKS

RTV SILICONE
Sold for use as an automotive sealant, RTV is rated to 650°F. It's more flexible than fireblock caulk, which tends to dry and fall out, so it can be a good choice for use around chimneys. Small quantities can be bought at auto-supply stores, but for caulk-gun tubes, Amazon .com is a good source.

ACOUSTICAL SEALANT
Meant for soundproofing, acoustical sealant never hardens, and it accommodates the normal movement of building materials without cracking. You might have to go to a commercial drywall supplier to find it.

SPRAY FOAM
Ranging in price from about $50 to over $100, foam guns make applying spray foam easy. Cans of foam for guns come in several varieties, from minimal-expanding for use around doors and windows to gap-filling for higher-volume applications. It's widely available online and at lumberyards and home centers.

SEAL THE BASEMENT WALLS OR THE

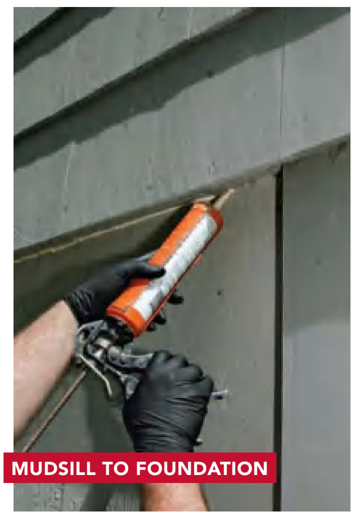
Whether to seal the foundation walls and slab or the subfloor above depends on factors unique to each house. When the basement is conditioned, the foundation walls and slab must be sealed because even though they are underground, air still can leak through the soil. If there are insulated foundation walls or ducts in the crawlspace or basement, use the wall and slab as the air barrier. If the subfloor consists of lumber planks, which leak a lot of air, it's probably easier to seal the foundation walls and slab. Bulkhead doors to the outside are big leaks, but it still might be easier to install a weatherstripped and insulated door at the bottom of the stairs than to seal the subfloor above.

CONCRETE PENETRATIONS

Apply spray foam around sump-pump pits as well as where utilities such as water lines, waste pipes, gas pipes, and oil fills enter the space.

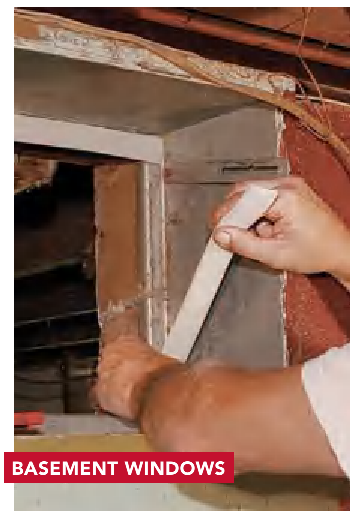
RIM JOIST

The rim joist is prone to air leaks from the multiple gaps: mudsill to rim joist, rim joist to subfloor, and butt joints in the rim joist itself. Install rigid-foam insulation in each joist bay, and seal its perimeter with spray foam.



MUDSILL TO FOUNDATION

Even mudsills set on foam gaskets have gaps. Seal the perimeter with caulk from either the inside or the outside.

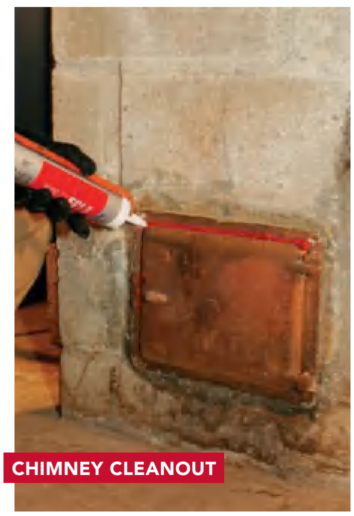


BASEMENT WINDOWS

Basement windows are often loose-fit sashes in cast-in-place frames. Use foam gaskets and foam rod to block air leaks.

SLAB TO FOUNDATION

Seal this gap, as well as any cracks in the walls or floors, with masonry sealant.



CHIMNEY CLEANOUT

Seal the perimeter of the door to the frame with RTV silicone. The sealant can be cut away and then replaced when the door is opened for cleaning.

BASEMENT CEILING

Use the first-floor subfloor as the air barrier if it's plywood or OSB, if the joist cavities are uninsulated, and if there are few ducts in the basement or crawlspace. If the basement or crawlspace is damp, has dirt floors, or has walls built of unmortared stone, air-sealing the subfloor helps control moisture. In houses with those issues and leaky board subflooring, seal the subfloor with several inches of spray foam. You may also need to dry out the foundation. In all cases, the door to the first floor requires weatherstripping.

TUB OR SHOWER DRAIN

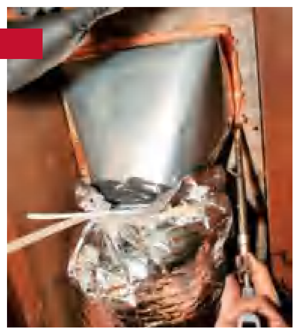
Piece in rigid foam around the pipes, gluing it to the subfloor with caulk or sealant. Fill the gaps with expanding foam.

PIPE AND WIRE HOLES

Seal the space between the framing and the wire or pipe with foam or acoustical sealant.

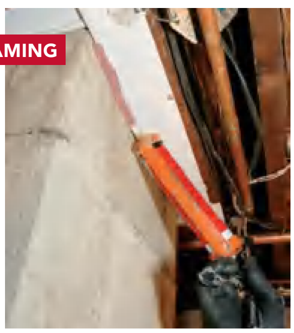
DUCT BOOTS

Seal to the floor with foam or acoustical sealant.



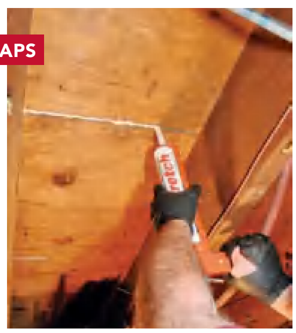
CHIMNEY TO FRAMING

Bridge the space with metal. Seal and fasten it to the framing, and seal it to the chimney with RTV silicone or fireblock caulk.



SUBFLOOR GAPS

Apply acoustical sealant or a flexible caulk to the joints.



the hole size and surrounding materials. The energy savings usually pay for the cost of air-sealing within a few years—almost immediately, in fact, if you do the work yourself.

Air-sealing keeps conditioned air inside the house, but it also improves the performance of insulation such as fiberglass, cellulose, and mineral wool by stopping air from moving through it. In addition, because moisture vapor piggybacks on leaking air, air-sealing reduces the possibility of condensation developing in building cavities, which can lead to mold and decay. It's also a first step to adding fibrous insulation to an attic in a cold climate. This type of insulation alone does not prevent warm, moist air from escaping the living space. Finally, air-sealing can block gasoline or CO fumes from an attached garage, or moldy air from a crawlspace. Air-sealing does make it more important to vent bathroom exhaust fans and clothes dryers to the outside.

Air moves in and out of houses due to pressure differences between the inside and the outside. The three main forces driving pressure differences are the stack effect, wind, and mechanical fans. Although wind and fans may be important drivers in warmer climates, the stack effect is often the dominant cause of air leaks in heating climates. The stack effect happens when warm air rises and escapes through holes high in the house, much like how a chimney works. Although it's a weak force, it operates constantly, so it can account for a lot of air movement and energy loss.

Determine your air barrier

Air-sealing starts with deciding which building planes to use as air barriers. A building plane can be the exterior sheathing, subfloor, or drywall. One way to visualize the air barrier is to look at a section drawing of the house and find a continuous line that encloses the living quarters. The insulation should contact the air barrier directly. Generally that means the air barrier is the drywall or sheathing along the exterior walls, the top-floor ceiling or roofline, and either the foundation wall and slab or the first-floor sheathing. Once you've identified the air barrier, look for leaks in it and seal them up, starting with the biggest ones in the attic and the crawlspace or basement.

Finding the holes

Although a visual inspection can find plenty of leaks, it's easier to pinpoint them by pres-

surizing or depressurizing the house and feeling for drafts with your hand or using a handheld smoke puffer. The smoke moves toward a hole if the house is being pressurized, or away from a hole if the house is being depressurized. It's better to pressurize the house when you are using smoke inside to find leaks, and to depressurize the house when you are using smoke outside the living space. Professionals use a blower door for this, a tool that combines a high-capacity fan with a fabric-covered frame that fits in an exterior doorway. A manometer attached to the fan measures the air-leakage rate of the house to predict its performance or to determine rates of air leakage and assess the progress of air-sealing work.

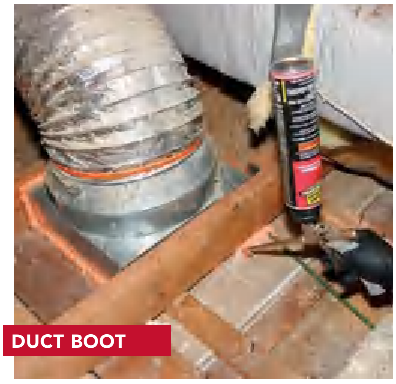
Blower doors cost about $2600, though, and they aren't commonly available to rent. You can sometimes depressurize a house enough to find air leaks by turning on the exhaust fans, central vacuum, and clothes dryer all at once. But in very leaky houses, that may not create a noticeable pressure difference. Another option is a powerful (5000 to 10,000 cfm) drum fan. One can be had for under $150 (I have a 24-in. shop fan from Harbor Freight) and can be fit into a piece of plywood that mounts to a door or window, creating a low-tech, homemade blower door.

Close all windows, doors, chimney dampers, and attic hatches to maximize the pressure difference. Exhausting air from a house may suck air down chimneys, so turn off combustion appliances such as gas ranges, furnaces, boilers, water heaters, or clothes dryers. Make sure that fireplaces or woodstoves have been out for 24 hours. Clean the ashes out of the firebox to avoid sucking them into the house, and wash potentially lead-contaminated dust from around windows in pre-1978 houses. If you have vermiculite insulation in the walls or attic or otherwise think there may be asbestos in the house, consult an asbestos-abatement specialist before doing any air-sealing. Remember to turn the appliances back on and to relight pilot flames when the work is done. □

Editorial adviser Mike Guertin is a contractor in East Greenwich, R.I. Rob Sherwood is a senior project manager with Conservation Services Group in Westborough, Mass. Photos by Andy Engel, except where noted.

SEAL THE ATTIC

In most homes, the drywall ceiling dividing the living space from the attic is the best air barrier at the top of the house. Seal leaks from above, and cover attic accesses such as stairs or scuttles with a foam box such as the Battic Door or ones available at home centers. We sometimes encounter ceilings covered with tongue-and-groove planks or acoustical tiles and no drywall behind them. These ceilings are nearly impossible to air-seal, so it's easier to seal these houses at the rafter plane by spraying a layer of foam against the underside of the roof and sealing off any attic ventilation. When there is no attic, such as with many sloped ceilings, the drywall still can be used as the air-control layer, but air leaks have to be sealed from inside the living space.



DUCT BOOT

Holes in the ceiling for duct penetrations are usually oversize and can leak significant amounts of air. Seal around them with spray foam or acoustical sealant.

RECESSED LIGHTS

These are notorious for leaking air. The first option is to replace a recessed can with an airtight model or a ceiling-mounted fixture, but you also can build an airtight box around lights that have thermal cutoffs as long as you observe the manufacturer-required clearances.

FRAMING AROUND CHIMNEYS

Insulate the space between the chimney and the framing with mineral wool, then bridge the space by bedding sheet metal in acoustical sealant and screwing it to the framing. Seal the metal to the chimney with RTV silicone or fireblock caulk.

Top-right photos, this page and facing page: Mike Guertin

DRYWALL GAPS

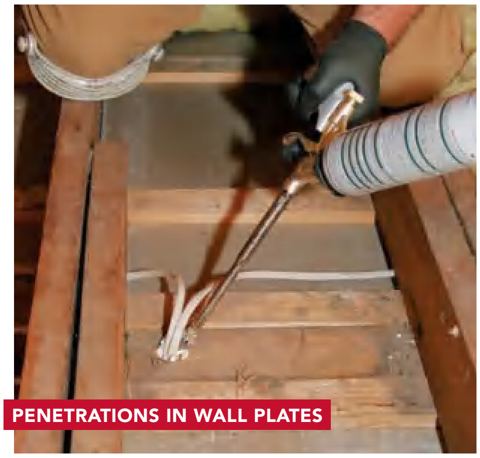
Added up, the gaps between the wall and ceiling drywall and the top plates can amount to a large open area. Seal gaps up to 1⁄4 in. with acoustical sealant and larger gaps with spray foam.

BALLOON FRAMES

Often found on gable walls, open stud bays conduct air from inside the house into the attic even when they are filled with fibrous insulation. Block the bays with wood or rigid foam sealed to the framing.

UTILITY BOXES

Foam or caulk the gap between drywall and electrical boxes, duct boots, and bath fans. Seal holes in electrical boxes, or encase smaller boxes with expanding foam.



PENETRATIONS IN WALL PLATES

Fill holes in the plates and gaps around wires and pipes with spray foam or acoustical sealant.

CHASES AND SOFFITS

Large breaks in the ceiling drywall often occur at utility chases, at corbeled chimneys, and above soffits. Block these holes with rigid materials (foam, plywood, OSB, drywall), and seal them to the surrounding framing and drywall.

Dedicated combustion air. *In tight houses, boilers and similar appliances should be supplied with air through a duct leading directly to the outside.*

Can you make a house too tight?

After air-sealing, have a knowledgeable HVAC technician or energy specialist make sure that your house has enough fresh air for your combustion appliances. Air-sealing can tighten a house to the point where combustion appliances don't receive enough make-up air to perform well. Atmospheric combustion appliances can be a health hazard in a tight house. The exhaust gases from a fireplace, woodstove, furnace, or water heater can be sucked down the flue by exhaust fans. Combustion appliances, or the area they operate in, should be outfitted with air intakes ducted from the outside. Broan makes a motorized damper that can be wired to open when the boiler or furnace fires, providing combustion air when needed while otherwise keeping outside air where it belongs. Intake ducts can connect directly to the burner on some models.

Tight houses can suffer from poor indoor-air quality if water vapor, VOCs, CO_2, and odors build up. You may need mechanical ventilation to bring in fresh air and exhaust stale air. In a balanced ventilation system, fans draw in and exhaust air at the same rate. An improvement to a basic balanced ventilation system is to use an energy-recovery ventilator (ERV) or a heat-recovery ventilator (HRV), both of which transfer a large percentage of the energy from the air being exhausted to the incoming fresh air.

Build a Risk-Free

Capturing this additional living space correctly and confidently requires

Finishing a basement can create extra living space with far less cost and complexity than an addition that expands the home's footprint. Perhaps for that reason alone, finishing a basement is a popular project for many homeowners. But a well-designed basement remodel is much more than an assembly of studs and drywall thrown up over a foundation wall, then trimmed and painted. Understanding and managing the risk of moisture and bulk water are imperative to developing a successful basement design, as is getting the insulation and air-sealing details right.

By assessing your site and basement accurately, and detailing your foundation floor and walls appropriately, not only can you improve the comfort, health, and efficiency of your home, but you can tackle the fit and finish of your basement with complete confidence in its durability and longevity.

Economics of performance

As with all construction projects, risk and performance in a basement remodel exist on a sliding rule of cost. Minimizing risk, providing durability, and ensuring proper performance come with a price. But when is good enough really good enough? It is easy to think of a basement as "cheap" space, but if the remodel is not well planned, it could easily be an inexpensive project that leads to expensive problems down the road. Improper water management can lead to health and durability risks; improper thermal management can lead to

MANAGE RISK AND REAP THE REWARDS

Risk is related directly to the threat of water and moisture in the basement. The more water challenging the foundation, the higher the risk level.

Because no two basements are alike, each one demands its own method for keeping the space below grade dry and healthy. While finish and furniture

LOW This basement was a 1757-sq.-ft. remodel for clients looking for a family room, a fitness area, and a recreation area. The design is enhanced by a full-height walkout, which allows lots of daylight to enter the family room. This low-risk basement had an existing perimeter drain that emptied to daylight, but there was no evidence or history of water intrusion. The foundation wall was insulated with 2 in. of closed-cell foam, while the wood-framed walkout was insulated to R-19 with cellulose.

MODERATE This 1616-sq.-ft. basement remodel added a media room, a bar and recreation area, a fitness room with a flat-screen TV, and a large pantry at the bottom of the basement stairs for storing bulk items. The homeowners were looking for a casual environment for entertaining and a place for their three children to be with their friends.

Finished Basement

a careful approach to the site and foundation

BY STEVE BACZEK

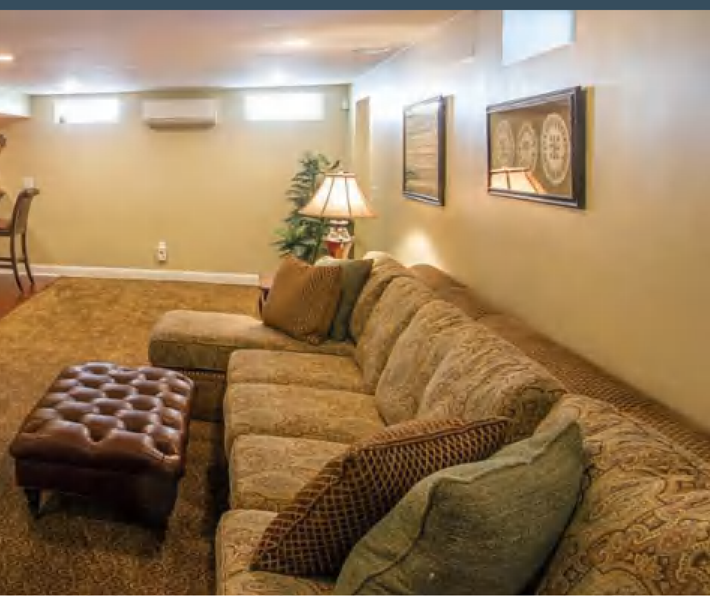
comfort risks. When it comes to considering the budget for a basement remodel, it's helpful to follow the general guideline that as cost decreases, risk increases. The challenge is to find a suitable balance between cost and risk.

Rating the conditions

Because of the below-grade location of most basements, the existence of water is generally the measuring stick of risk. I typically rate existing foundations as having low, moderate, or high levels of risk. To me, low-risk foundations are not challenged at all by water infiltration. They are most often located in a high, well-drained area, and they have no evidence of water problems from the walls or the slab. Remodels should still be detailed carefully, though, since dramatic weather-related water events could occur at any time. I have also seen basements compromised because site conditions changed naturally, or more frequently, because neighboring properties were developed.

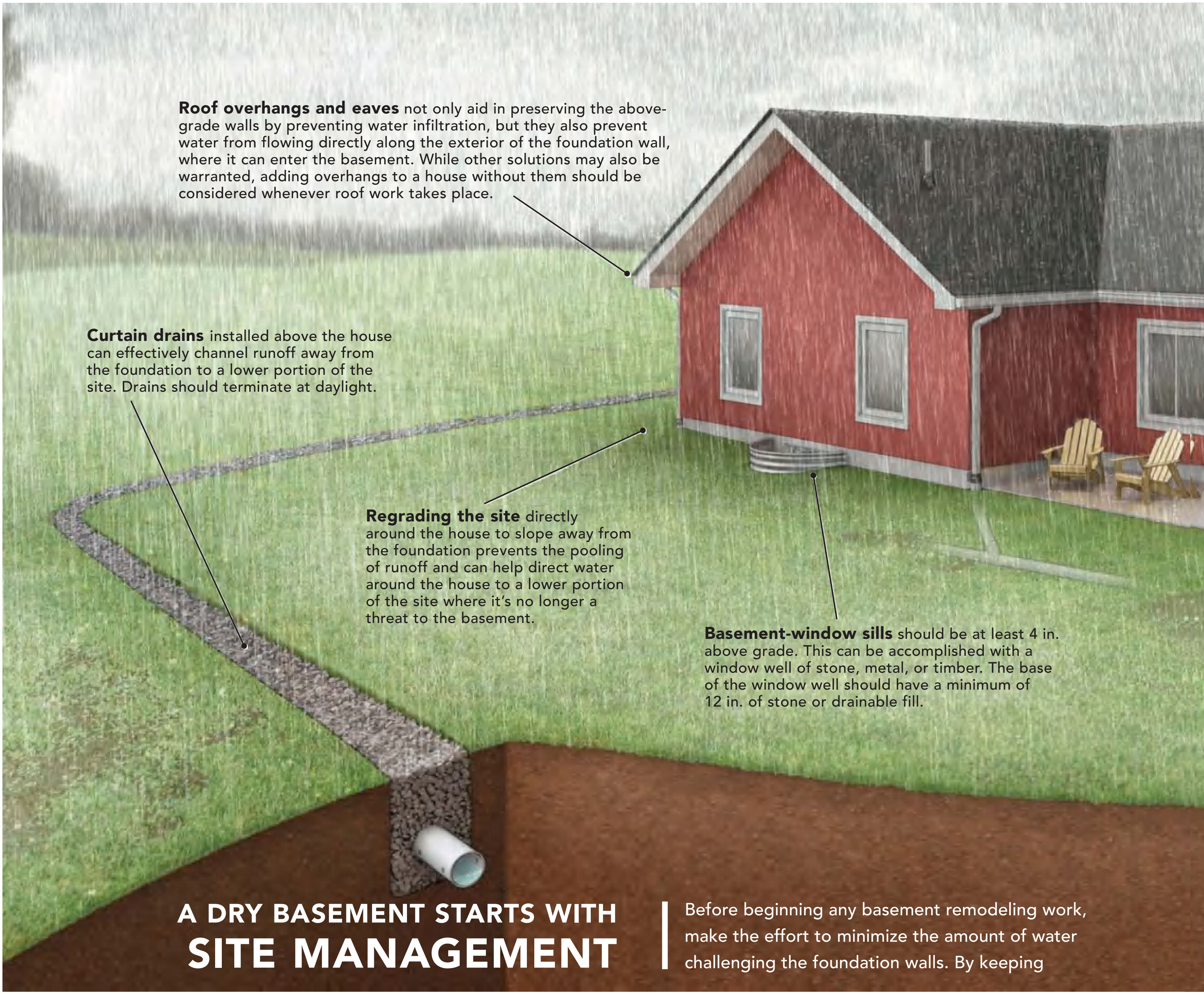
A basement with a moderate risk level has seasonal challenges. In colder climates, water from the spring thaw can saturate the ground. In warmer climates, water might become a problem during the rainy season. Regardless of the source, a moderate-risk scenario has water issues for up to half of the year. If you've lived in the house for a period of time, you certainly know if and when water issues are a problem. If you're working on a home without historical context, look for evidence of bulk water in the basement in the form of stain-

selection can be inspired by other projects, it's important to design your finished basement around your specific needs and challenges. The approach to low-, moderate-, and high-risk projects outlined here is not theoretical. It can be trusted in practice. Below are three of the author's designs, built by Two Storey Building of Bolton, Mass., that afforded his clients the additional living space they dreamed of while also offering them peace of mind.



The basement was at a moderate risk level and required a new perimeter-drain system. In this remodel, the foundation walls were insulated with 2 in. of polyisocyanurate. A 2x4 stud wall was then framed over the rigid foam and filled with R-15 unfaced batts. Finishes in this space are casual and comfortable, and they are easily replaced if needed.

HIGH This design called for a media area, a kitchenette, and a fitness area with a full bath. The remodel was considered high risk, as the space endured occasional water intrusion. To provide proper water management, a drainage curtain was placed on the interior face of the foundation from the mudsill to a new perimeter drain. The walls were insulated with 2 in. of closed-cell spray foam placed between the 2x4 stud wall and the foundation wall. Then an R-15 unfaced batt was added to each wood-framed stud cavity.



A DRY BASEMENT STARTS WITH SITE MANAGEMENT

Before beginning any basement remodeling work, make the effort to minimize the amount of water challenging the foundation walls. By keeping

ing on the slab and/or mineral streaks along the foundation walls. Your new neighbors might also be able to provide some insight into existing conditions, but keep in mind that every property is unique. Just because your neighbor's basement is dry doesn't mean yours is.

A high-risk basement faces water infiltration for more than six months of the year. Water might even be a daily challenge. High-risk basement remodels can be managed effectively, but demand a system with redundant layers of water management.

Site and foundation assessment

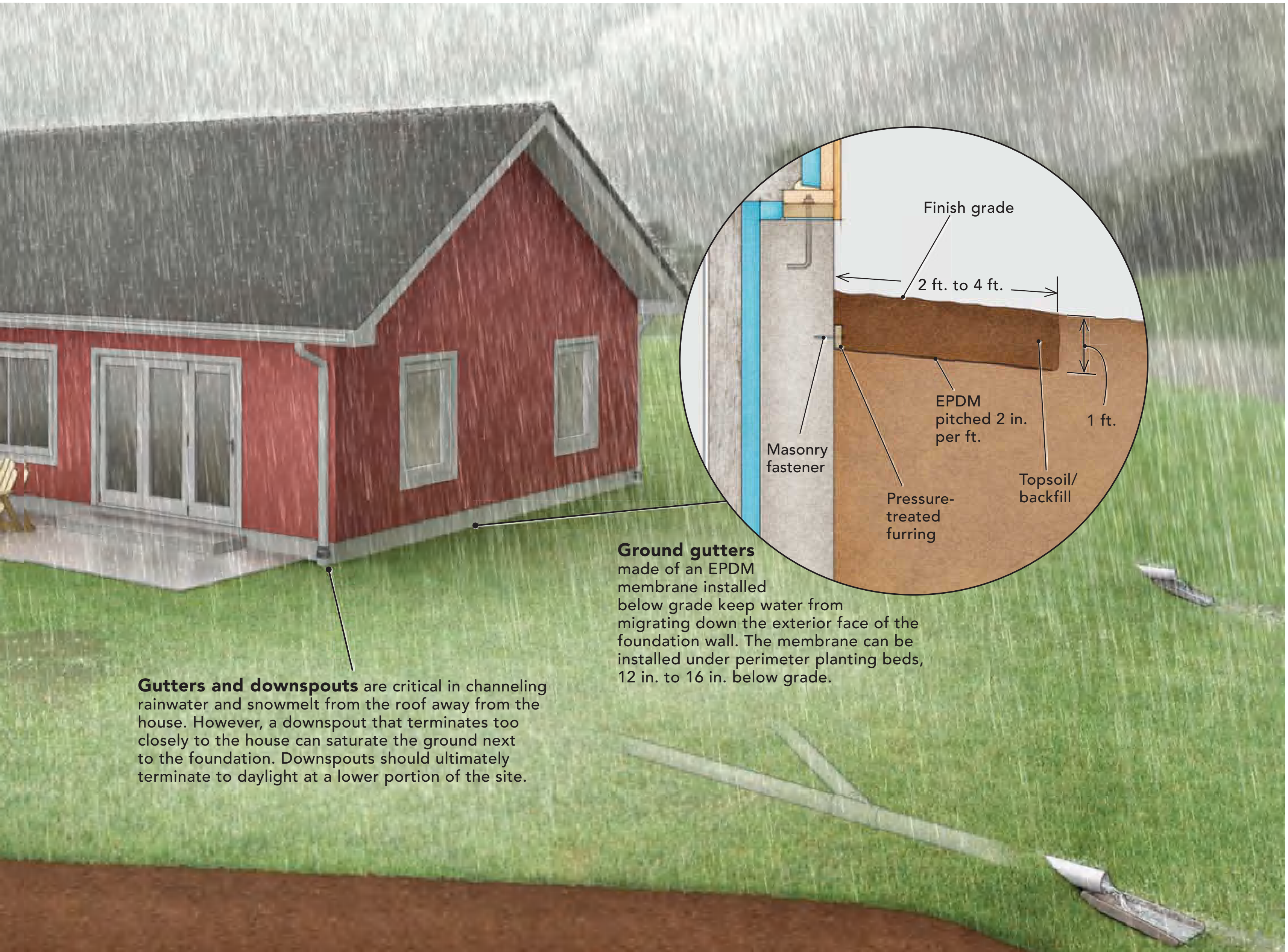
The initial steps in designing any finished basement are straightforward. First, if any water exists on the site, try to minimize the amount of it near the exterior of the foundation before beginning your work on the inside. The less water you have to deal with, the smaller the problem will be, and therefore, the smaller and less expensive the management system needs to be.

Once the site is analyzed and a plan for correction or improvement is developed, the foundation itself needs to be assessed. Different foundation types perform differently and can demand different approaches to management. Stone, brick, concrete block, and concrete all have specific characteristics that challenge a finished basement. Stone, brick, and concrete-block foundation walls are all mortared systems. The amount of mortar and the manner in which it was laid (neat and full vs. sloppy and spare) help determine the ability for water to penetrate the foundation wall. Because of their continuous casting, concrete walls offer a more formidable defense to the infiltration of groundwater. Make no mistake, though—if water exists, it will get in eventually.

Managing moisture

Moisture in its vapor form is usually not a cause for concern in a basement. It only becomes a problem when it is given the opportunity

Drawings: Christopher Mills



storm water, snowmelt, and runoff away from the house, you decrease the risk level of the basement renovation, which can help reduce the cost and complexity of the remodeling work. Here are the primary things to keep in mind as you create a strategy for keeping water away from the foundation.

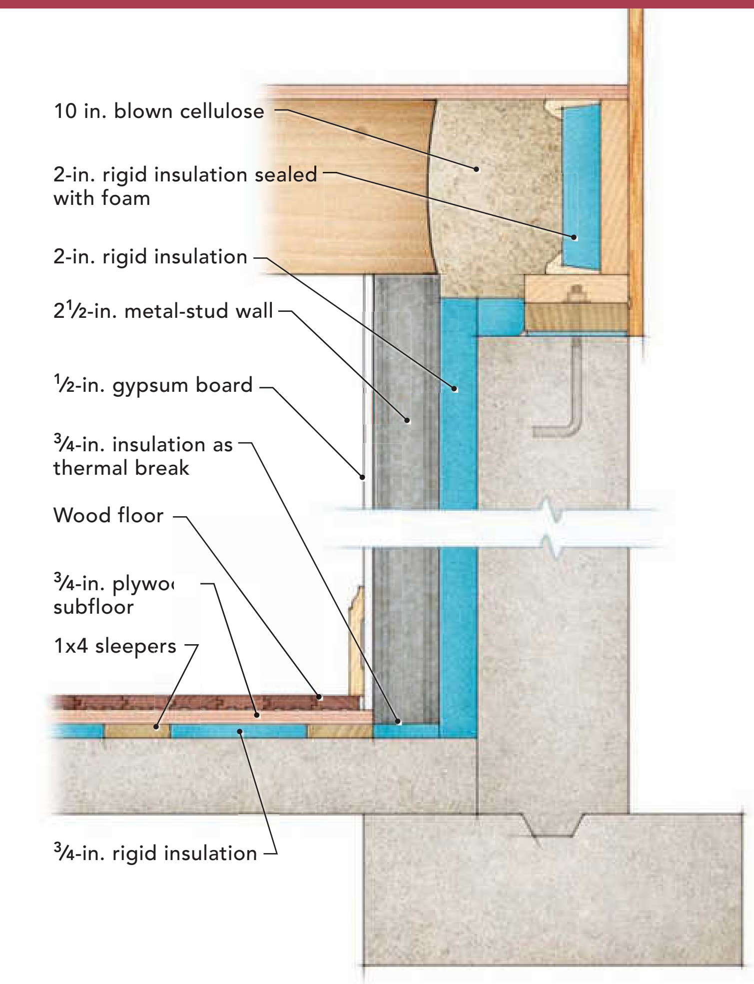
to cool and compress to its saturation limit and condense on cool surfaces. For this reason, controlling surface temperatures in the basement is critical. For example, I recommend thermally breaking the framed walls from the concrete slab with a piece of rigid insulation under the bottom plate. This prevents vapor from permeating through the slab and condensing on the cool wood framing, where it could conceivably cause rot and mold growth.

Some builders try to control vapor by applying vapor barriers between the slab and finish flooring or between the foundation walls and the finished space. In some cases, this approach might be successful, but I tend to stay away from barrier systems in favor of management systems. I typically allow the vapor to migrate into the basement and then manage the level of moisture in the basement air with my mechanicals. A heat-pump water heater, for instance, provides partial dehumidification of the air as it heats the domestic water supply. This appliance, though, needs its own drain line for condensate.

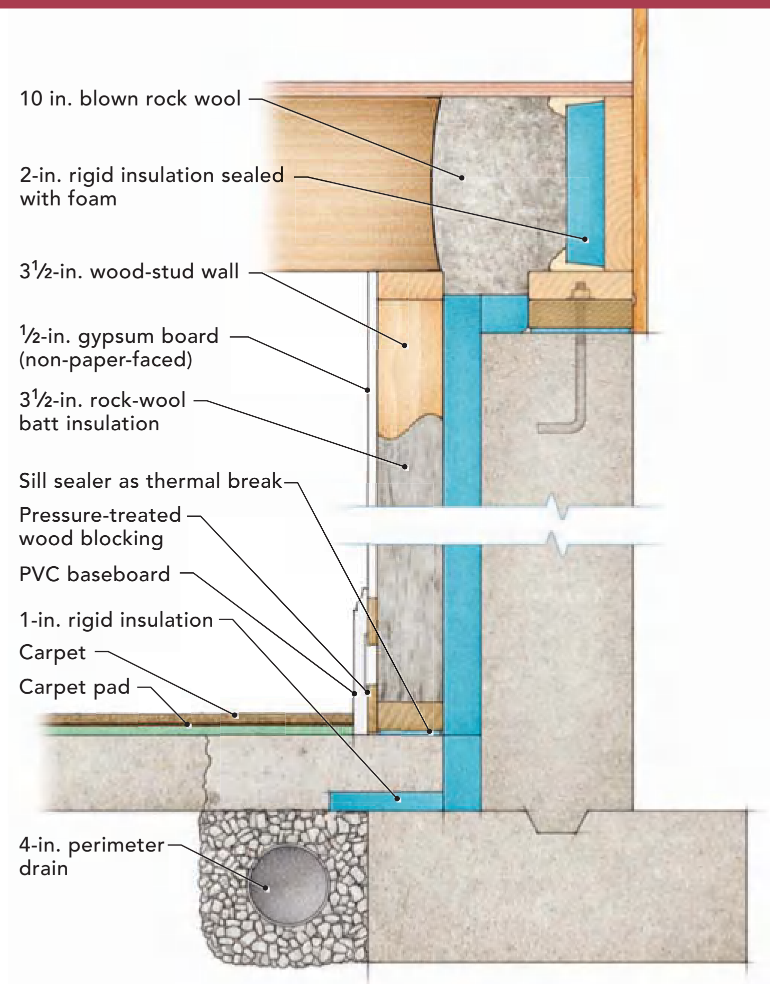
When it comes to bulk water infiltrating the basement, the strategy is straightforward. The objective is to manage, collect, and discard it. Depending on the level of risk and the amount of water infiltration, an appropriate drainage plane must be employed to manage this water. With a moderate level of risk, such as where water moves through the wall by capillarity or saturation, the drainage plane could be as simple as a layer of rigid insulation applied to the foundation wall and its seams taped. At a higher level of risk, where bulk water comes through the wall, a drainage curtain or drainage mat would be needed. A drainage curtain needs to be linked physically to a subslab perimeter-drain system in cases where a footing drain isn't already in place. This is the "collect" part of the strategy. After the infiltrated water is collected, it is directed to a sump pump for discharge. (For more on sump pumps, see "What's the Difference?" *FHB* #248.) If the exterior grade allows, however, the perimeter drain can be directed to daylight at some point on the property. By virtue of its subslab posi-

BALANCE RISK
WITH THE RIGHT DESIGN

There are two simple rules when it comes to designing a finished basement. First, water is never stopped, halted, or detained; it is managed. Second, Mother Nature and Father Physics are formidable opponents, with a very long history of success. Believing that we can win against their natural forces



LOW RISK



MODERATE RISK

tion, the perimeter drain handles any groundwater challenging the slab from below.

Insulation and air-sealing

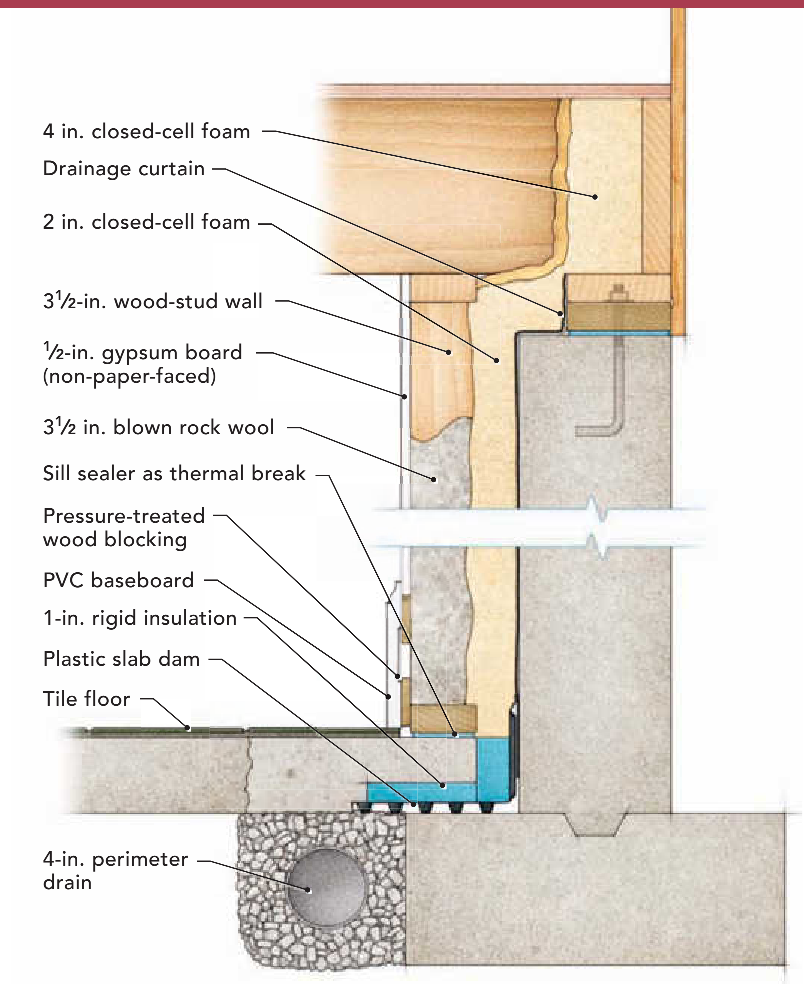
In most unfinished basements, moisture issues cause few problems because a leaky above-grade envelope allows the moisture to dry. In many homes, though, attempts have been made to separate the basement from the conditioned living space above with batt insulation installed in the first-floor joist bays. These attempts usually fail, since air movement between the floors goes unchecked. In addition, as the lowest point in the house, the basement is subject to the highest negative pressure (air infiltration) due to the stack effect. Whether the basement is insulated or not, the mechanical system located there is unavoidably tasked with conditioning the basement. In many cases, adding a proper thermal barrier in the basement allows the mechanical system to work less and still be able to provide the required heating or cooling of the insulated basement.

When it comes to insulating the basement, there are code-minimum R-values that vary based on where the home is located. My approach is to provide an R-value that is proportional to my thermal goals above grade. I typically strive for a basement-wall R-value that is at least half of my above-grade wall-insulation value. My target slab R-value is typically at least half of my basement-wall R-value. At a minimum, these numbers usually work out to an R-10 slab and an R-20 foundation.

Rigid insulation, spray foam, blown insulation, and batt insulation all have their place in certain basements. I typically consider batt or blown insulation to be an additional level of insulation rather than my primary insulating method. I refrain from putting any of them directly against the foundation wall for a couple of reasons. First, they allow air movement between the foundation and the wall assembly, making it more difficult to control the surface temperature of the framing and drywall. Second, water permeating the foundation can easily move through the insulation and damage the framing and drywall.

Photo facing page: Charles Bickford

is simply a fantasy. Water management that aligns with their rules is the path to ultimate success. The following examples illustrate adherence to these rules and insight into the proper approach to waterproofing, insulating, and finishing foundations that vary in risk level.



HIGH RISK

Code considerations

Many code requirements for basements apply directly to occupant health and safety. Here are a few worth investigating before moving forward in any basement design.

- Ceiling height or beam height is always a challenge in basements, especially in older homes. According to IRC R304.3, minimum ceiling height of a habitable space is 7 ft.
- Egress demands increase dramatically when the basement remodel includes adding bedrooms. Refer to IRC 310.1.
- Proper alarms for smoke, fire, and carbon monoxide should be installed and maintained in accordance with IRC R314 and R315.
- Sealed-combustion mechanical equipment that separates the combustion air within the device from the basement air is required in some jurisdictions and is a good idea in all of them.
- Natural ventilation is a calculated requirement in many jurisdictions. Start by researching IRC R303.
- Radon testing and mitigation are required in some jurisdictions. Radon can become a problem as a basement gets tighter.

I like to control the surface temperature of the foundation wall with rigid foam or spray foam. After one of them has been installed, I determine the risk of adding batt or blown insulation. I tend to avoid batt or blown insulation in high-risk basements, and I use it sparingly or as bulk-fill insulation in lower-risk basements.

In terms of air leakage, the concrete walls and slab do a fine job of providing air-barrier continuity along their surfaces. With a stone, brick, or concrete-block foundation, the air barrier becomes more of a challenge. In these cases, I tend to use a drainage curtain, rigid insulation with sealed joints, or spray foam as the primary air barrier linking the slab to the mudsill.

Fit and finish

When it comes to finish materials in the basement, I have heard hundreds of opinions on which ones to use, where to use them, and why. I rely on my initial risk assessment to guide me in material selection with my clients, but I try to accommodate their wishes. In most cases, the installation methods of the selected materials are of prime importance, not the materials themselves. For example, if drywall is to be used in a moderate- or high-risk basement, then I will install a tall (8-in. or 10-in.) synthetic baseboard and hold the bottom edge of the drywall just under the top of the baseboard, which I will fasten to blocking. If the basement incurs a flood, the drywall is likely not to be part of the resulting problem. If a client desires carpet in a low-risk basement, I probably won't have a problem with installing it wall-to-wall. In basements of moderate and high risk, a better option is either an engineered-wood floor or a tile floor with large area rugs. Area rugs are easy to remove, clean, and reuse if they are part of a flood.

In summary, my approach is pretty simple: As risk increases, materials used in a finish basement should be less permanent or more resistant to moisture and water. □

Steve Baczek is an architect in Redding, Mass. Photos by David Fell, except where noted.

howitworks

THE MECHANICS OF HOME BUILDING

BY ROB YAGID

Fiberglass-batt insulation

An architect recently described the 2x6, fiberglass-batt-filled walls in his new home as performing at R-19—presumably because he used R-19 batts. The statement is a reminder that lots of builders and architects—even after all the research and the testing that have been done—still don't understand the material.

So what's wrong with that architect's "R-19" wall? Although not impossible, it is extremely difficult to install fiberglass batts well enough to achieve that R-19 benchmark. More often than not, job-site conditions and common installation mistakes (right) compromise the thermal resistance of the batts, and the way they perform after installation—their real-world performance, that is—ends up being a diminished version of what's promised on the label (far right). To determine if fiberglass-batt insulation is right for your next project, you need to understand how it works.

Rob Yagid is the editor of Fine Homebuilding.

Torn vapor retarder

Some installers mishandle the batts and rip their vapor-retarder facing. Don't worry about small tears, but if there are large holes in the facing, repair them with housewrap tape to restore the integrity of the vapor retarder before you hang the drywall.

Sloppy utility detail

Batts should be cut precisely so that they fit snugly around electrical boxes, and they should be split and fitted around wires and pipes so that the fiberglass is not compressed, which would reduce its R-value.

Compression

Batt compression diminishes rated R-values. Most R-19 batts (R-3.04 per in.) are 6¼ in. thick. When the batt is compressed into a 5½-in.-deep stud cavity, the overall R-value decreases to R-18. The R-value per inch increases to R-3.27, but the overall R-value is what really matters. Stuffing a batt into place or pinching it behind obstructions reduces its overall R-value even more.

Photo: Rob Yagid. Drawing facing page: Rodney Diaz.

Incorrect fastening

Batts with vapor-retarder facings should be stapled to the face of the studs. Otherwise the batts become overly compressed along their edge, which reduces their overall R-value further.

Gaps

Gaps between framing and batts can lead to energy losses and to durability issues stemming from condensation that forms in the wall when warm air comes into contact with cold, exposed surfaces.

A fiberglass batt will perform best if it's installed in an airtight cavity and if it's in full, uniform contact with the interior or exterior sheathing, as well as the studs and top and bottom plates.

LABELED VS. REAL-WORLD PERFORMANCE

R-19-labeled batts don't create R-19 walls. Studies at Oak Ridge National Laboratory show how conventionally framed 2x6 walls filled with standard, low-density R-19-labeled fiberglass batts actually perform (graph below).

Installation has a significant effect on insulation performance, but so does the very nature of wood-framed structures, something that's often forgotten.

BATTS ARE EASY TO INSTALL INCORRECTLY

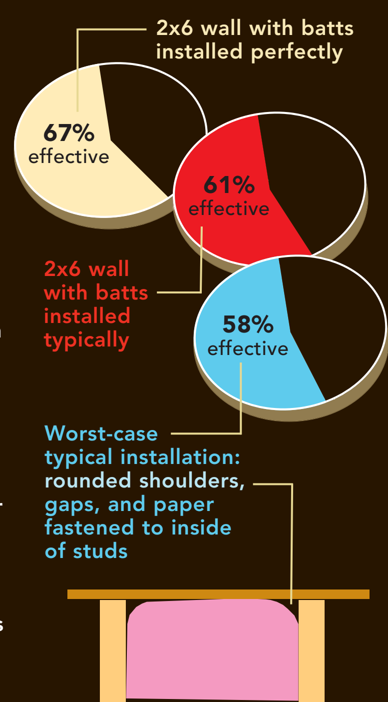
The Residential Energy Services Network (RESNET) has created a three-grade criterion for assessing the quality of new insulation installed in homes getting a home energy rating. The ideal installation is rated as Grade I, which demands the following:

- Batts must be installed according to the manufacturer's directions.
- Each stud bay must be filled completely with minimal gaps or compression around obstructions. No more than 2% of the insulated area can be compressed, and there can be no areas of missing insulation.
- The insulation must be cut or split so that it fits snugly around electrical wires or plumbing running through the stud bay.
- The insulation must be in full, uniform contact with either the exterior or the interior sheathing. With a putty knife, you can push a batt so that it fits tightly into the back corners of the stud bay, eliminating rounded shoulders.
- The insulation must be installed to full rated thickness, allowing for the 2% compression. If insulation is uniformly compressed, the lower resulting R-value must be taken into account.
- Each insulated stud bay must be enclosed on all six sides, though there are certain exceptions for floors, ceilings, and rim joists.

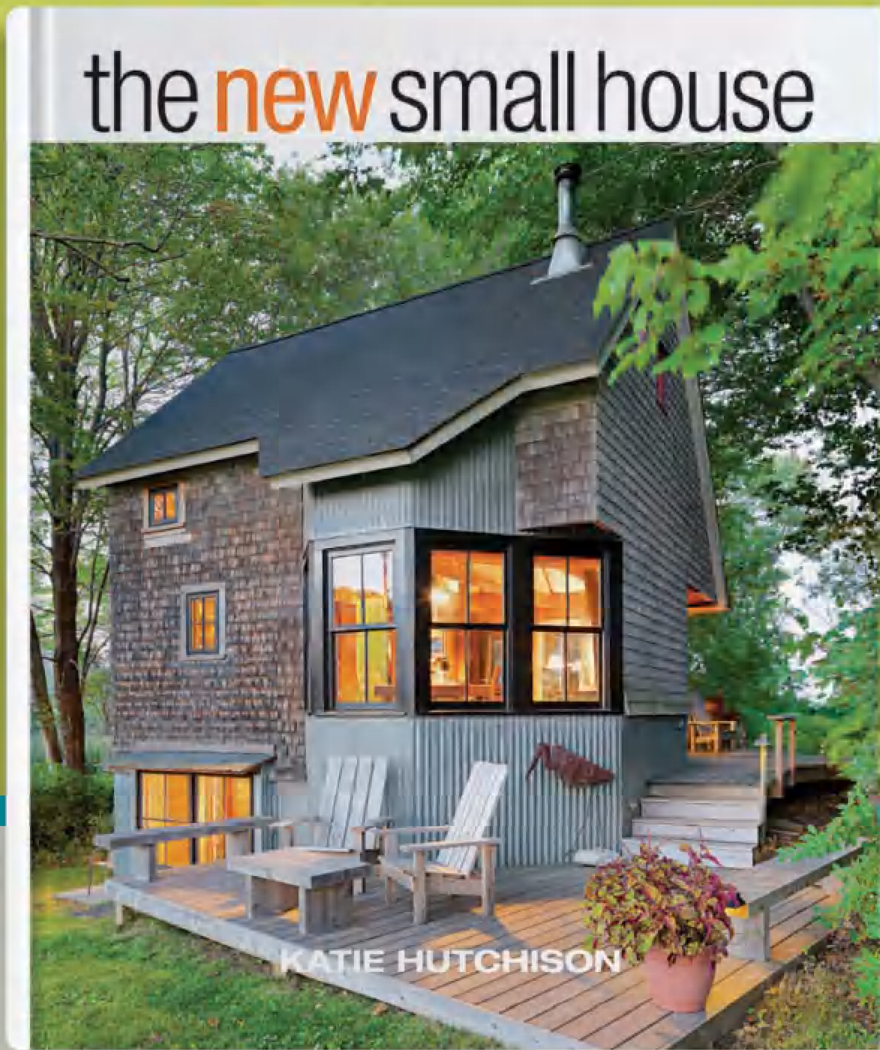
REAL R-VALUES ARE LOWER THAN LABELED R-VALUES

While it's difficult to install fiberglass insulation perfectly, batts will perform at their rated R-value if used correctly. However, cavity insulation is only part of the equation when it comes to a wall's true performance.

The Oak Ridge National Laboratory study looked at whole-wall R-values, which take into account flaws in batt installation and the variety of structural elements that make up approximately 25% of the wall, such as studs, headers, and plates. The findings show that a 2x6 wall insulated with R-19 fiberglass batts that have been installed perfectly actually performs at an R-value (12.8) that's more than 30% lower than what the labeled R-value suggests.



The thermal bridging that so drastically reduces whole-wall R-values is most simply and effectively handled with the application of exterior rigid foam. Thermal bridging also can be reduced by designing and building with OVE (optimum-value engineering) framing, which reduces the amount of framing in wall and roof assemblies.



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